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MAY 2 0 1987
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AUG 1 2 1992

NRS 528

MONTANA FARMS BIOGAS/COGENERATION FEASIBILITY STUDY

Prepared by

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November 1984

Prepared for

Montana Department of Natural Resources and Conservation
1520 East 6th Avenue, Helena, Montana 59620
Renewable Energy and Conservation Program
Grant Agreement Number RAE-83-1028

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November 9, 1984

Mr. Ralph V. Morand, Owner/Partner
Montana Farms
Route 1, Box 63
Townsend, Montana 59644

14-1682-01

Subject: Final Report--Montana Farms
Biogas/Cogeneration Feasibility Study

Dear Mr. Morand:

In accordance with our agreement for engineering services dated July 11, 1984, enclosed is the final report on the Montana Farms Biogas/Cogeneration Feasibility Study. The report presents the findings of a technical and economic evaluation of three systems for anaerobic digestion of chicken manure and options for biogas/manure utilization.

The study found that production of biogas from layer manure is technically feasible. Close temperature control, adequate mixing, and control of digester pH are necessary to optimize the process.

The study also found that costs associated with biogas production and cogeneration of electricity and thermal energy cannot now be recovered through energy savings and sale. With 80 percent grant funding of the project cost, and a 10-percent per year increase in energy costs, however, System Option 1, Conventional Technology, would be less costly than the No Project Option. With System Option 1, Montana Farms would save about $26,000 during the 10-year analysis period, and additional money thereafter.

The uncertainties associated with the project are economic and not technical. We therefore recommend that Montana Farms seek grant funding for preparation of a final design for the project. With design drawings and specifications in hand, Montana Farms could obtain firm bids for construction of the project from local contractors. This would eliminate uncertainties associated with the cost of the project. Negotiation of contract provisions for power wheeling and sale would, similarly, eliminate uncertainties associated with the economic benefits of the project.

In closing, we wish to express our appreciation to the people of Montana Farms and at the Montana Department of Natural Resources and Conservation, Energy Division, for their assistance on this project. We look forward to working with you in the future.

Very truly yours,

BROWN AND CALDWELL

Robert M. Hunter

Robert M. Hunter
Project Manager

RMH:sjw
Enclosure

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SECTION 1

EXECUTIVE SUMMARY

This section presents a brief summary of the findings and conclusions of this research. Information contained in this summary follows the format of the body of the report.

SYSTEM OPTIONS AND DEVELOPMENT

Section 2 of this report presents a technical evaluation of three systems for anaerobic digestion of chicken manure and develops and evaluates options for biogas/manure utilization at the Montana Farms egg farm in Townsend, Montana.

Summary of Research

This research evaluated the feasibility of producing biogas from chicken manure and using the biogas as fuel to generate electricity and thermal energy to reduce the energy demands of the Montana Farms egg farm in Townsend, Montana. Montana Farms maintains an average egg-laying chicken (layer) population of 110,000 and an average growing chicken population of 40,000. The layers produce over 5,000 tons of manure per year.

This research compared three specific alternative systems for producing biogas and generating electricity and thermal energy. The evaluation considered the technical and economic advantages and disadvantages of each system. Each system includes manure collection, anaerobic digestion, generation of electricity and thermal energy, and stabilized manure disposal. The three systems are as follows:

1. Conventional technology--continuous anaerobic digestion of manure diluted to form a slurry in a heated, mixed reactor.

2. Innovative technology--continuous anaerobic digestion of manure in a semi-solid form in a heated, mixed reactor.

3. Low technology--anaerobic digestion of batches of manure in a heated, unmixed reactor.

Evaluations included comparisons of liquid versus solid manure collection, aged versus fresh manure digestion, ebullient cooling versus hot water cooling of the engine/generator, and stabilized manure land disposal versus drying and packaging of stabilized manure for sale as a soil conditioner. All evaluations considered the impact of cold weather operation and the technical aspects of

operating the anaerobic digestion process on manure with relatively high concentrations of ammonia and grit.

Laboratory-scale biogas production tests of each technology were conducted in parallel over a 120-day period using bacteria cultures that had been previously acclimatized to high ammonia concentrations. The tests allowed accurate predictions to be made of the quantity and methane content of biogas produced by each technology.

Conceptual designs of the three systems were developed on the basis of the results of these tests, measurements of the amount of manure produced, and tests of the composition of the manure. Capital and operating costs of each total system were estimated. These costs were compared to the economic and other benefits of the project. Costs and benefits before and after government incentives (e.g., tax credits, loan guarantees, etc.) were considered.

Resource Assessment

Montana Farms maintains a fairly constant layer population of 110,000 birds and a growing chicken population of 40,000 birds. The 110,000 layers are housed in three "high-rise" poultry houses.

Biomass Characteristics. Manure production and composition data were obtained during this study. Layer manure production rates were found to be fairly constant. An average manure production rate of 0.253 pound per day (ppd) per bird was measured.

The composition of both fresh and aged manure was analyzed. Fresh manure composition averages were as follows:

Total solids:	25.6 percent
Volatile solids:	18.4 percent
Ammonia-nitrogen:	8,900 mg/kg

Aged manure composition averages were as follows:

Total solids:	35.8 percent
Volatile solids:	16 percent
Ammonia-nitrogen:	12,800 mg/kg

Description of Laboratory-Scale Tests

Three experimental reactors were set up to measure the quantity and quality of biogas produced by anaerobic digestion of chicken manure. Reactor design criteria were selected to characterize the three anaerobic digestion technologies under study. Test reactor design criteria were as follows:

Technology	Feed, percent solids	Mixing	Detention time, days	Loading rate, kg VS/cu m/day
Conventional	7	Yes	20	0.15
Innovative	25	Yes	100	0.10
Low	7	No	30	0.10

Results of Laboratory-Scale Tests

Laboratory-scale testing of the three technologies produced the following results:

Biogas Production Rates. Biogas production rates varied among the reactors. The following biogas production rates could be achieved with the reactors operating within reasonable ranges of temperature (95-100°F) and pH (6.6 to 7.6):

Technology	Detention time, days	Biogas production rate, cu m/kg VS added (a) Average	Range
Conventional	10	0.40	0.35-0.45
	15	0.45	0.40-0.50
	20 (est)	0.50	0.45-0.55
Innovative	100	0.33	0.30-0.36
Low	20	0.33	0.30-0.36
	30	0.36	0.33-0.39

Biogas Composition. Average biogas methane content was as follows: conventional--57 percent; innovative--48 percent; and low--54 percent.

Mixing. Mixing had a significant positive effect on biogas production rate and composition. Accumulation of grit occurred in the unmixed reactor.

Temperature. Very significant increases in biogas production rates were achieved when reactor contents were held within 1 or 2 degrees of 95°F.

Ammonia Toxicity. Ammonia-nitrogen is known to be toxic to methanogenic bacteria. High ammonia-nitrogen and pH levels in the high-solids (innovative technology) reactor reduced biogas quantity and quality.

Salt Inhibition. Salt did not become concentrated enough to inhibit the digestion process.

Energy Use

Data on annual, monthly, and hourly energy requirements were obtained and analyzed. Both electricity and propane are used in significant quantities by Montana Farms.

Electrical Energy. Over the last three years, total annual electrical energy use has averaged over 600,000 kilowatt-hours (kwh) per year. In general, higher electrical energy demands occur during the warmer months when more ventilation is needed.

Propane Consumption. Propane is used for heating egg washing water and for space heating. Propane consumption has averaged 34,600 gallons per year during the last three years.

Development of System Options

System options were developed by conducting preliminary evaluations of system components to optimize each system.

Screening-Level Evaluations. Screening-level evaluations were conducted of the following:

1. Handling of solid versus liquid manure.
2. Digestion of aged versus fresh manure.
3. Ebullient (two-phase) cooling versus water cooling of the engine generator.
4. Stabilized manure/land disposal versus composting and sale.

The conclusion of the first evaluation was that solid manure handling would reduce system costs. Use of a small skid steer loader to collect the manure and deliver it to the digester feed system was recommended.

Handling of aged rather than fresh manure was found to significantly reduce capital and operating costs. A reduction in biogas and electricity production would occur, but the reduction would be minor.

Hot water cooling of the internal combustion engine used to drive the generator was selected. Shutdowns of the equipment will be minimized.

Drying lagoons were selected as the means of dewatering the digested manure. Composting and sale of stabilized manure was found to be technically feasible.

Because of uncertainties about compost transportation and bulking agent costs, and due to a lack of marketing information, it was recommended that composting be pilot tested prior to implementation at full scale.

Description of Systems. Based on the results of laboratory testing of three anaerobic digestion technologies and the findings of screening-level evaluations of system components, three biogas producing system options were formulated. Each system option included manure collection, anaerobic digestion, cogeneration of electricity and thermal energy, and manure disposal and/or reuse.

1. System Option 1: Conventional Technology. With this system, a mixing tank, a mixed anaerobic digestion tank, a cogeneration system, and manure drying lagoons would be provided. Manure would be diluted to 7 percent solids with water prior to digestion. The cogeneration system would have a rated output of 60.7 kilowatts (kw).

2. System Option 2: Innovative Technology. With this system, a live bottom feed bin would be used to feed undiluted manure to a mixing tank. Digester contents would be used for manure dilution. Two mixed anaerobic digestion tanks would be needed. The cogeneration system would have a rated output of 41 kw. Smaller drying lagoons would be necessary.

3. System Option 3: Low Technology. With this technology, a 7 percent slurry would be added to an unmixed digester consisting of a buried concrete tank with a rubber sheeting cover. The cogeneration system would have a rated output of 41 kw.

PROJECT ECONOMICS

An economic evaluation of the three systems was presented. The costs and benefits of each system were compared to the "no project" alternative.

Basis of Cost and Benefit Estimates

Costs and benefits of the three options were estimated using a consistent basis.

Capital Costs. Capital costs are expressed at mid-1984 price levels.

Operation and Maintenance Costs. Annual operation and maintenance costs were developed by applying unit labor costs to estimated annual manhour requirements.

Cost Savings and Revenue. Reduction in electricity and propane purchases would result in cost savings. Current rates were used to estimate initial year savings. Electricity sales revenue is based on wheeling power to Montana Power Company.

Tax Savings. Both tax increases and decreases were estimated. A 35 percent tax bracket was assumed.

Summary of Project Economics

A summary of project costs and benefits associated with each alternative is presented. Tabular summaries of capital costs, operation and maintenance costs, and project economics are given.

Comparison of System Options

An economic comparison of the system options is presented. Ten-year cumulative net costs of the options are given below:

Option	Ten-year cumulative net cost, thousand dollars
No project	138.50
Option 1	497.63
Option 2	570.86
Option 3	503.99

Sensitivity Analysis

The sensitivity of the apparent best action alternative, Option 1, to principal cost factors is analyzed. With 80 percent grant funding and a 10-percent per year increase in energy costs, Option 1 is less costly than the No Project alternative.

SECTION 2

SYSTEM OPTIONS AND DEVELOPMENT

This section presents a technical evaluation of three systems for anaerobic digestion of chicken manure and develops and evaluates options for biogas/manure utilization at the Montana Farms egg farm in Townsend, Montana. Included are a summary of the research, an assessment of the biomass resource, an analysis of on-farm energy requirements, development of system options, and a technical evaluation of the more promising options. Footnotes are indicated by superscript numbers.

SUMMARY OF RESEARCH

This research evaluated the feasibility of producing biogas from chicken manure and using the biogas as fuel to generate electricity and thermal energy to reduce the energy demands of the Montana Farms egg farm in Townsend, Montana. Montana Farms maintains an average layer population of 110,000 and an average growing chicken population of 40,000. The layers produce over 5,000 tons of manure per year.

This research compared three specific alternative systems for producing biogas and generating electricity and thermal energy. The evaluation considered the technical and economic advantages and disadvantages of each system. Each system includes manure collection, anaerobic digestion, generation of electricity and thermal energy, and stabilized manure disposal. The three systems are as follows:

1. Conventional technology--continuous anaerobic digestion of manure diluted to form a slurry in a heated, mixed reactor.

2. Innovative technology--continuous anaerobic digestion of manure in a semi-solid form in a heated, mixed reactor.

3. Low technology--anaerobic digestion of batches of manure in a heated, unmixed reactor.

Evaluation included comparison of liquid versus solid manure collection, aged versus fresh manure digestion, ebullient cooling versus hot water cooling of the engine/generator, and stabilized manure land disposal versus drying and packaging of stabilized manure for sale as a soil conditioner. All evaluations considered the impact of cold weather operation and the technical aspects of operating the anaerobic digestion process on manure with relatively high concentrations of ammonia and grit.

Laboratory-scale biogas production tests of each technology were conducted in parallel over a 120-day period using bacteria cultures that had been previously acclimatized to high ammonia concentrations. The tests allowed accurate prediction of the quantity and methane content of biogas produced by each technology.

Based on the results of these tests, measurements of the amount of manure produced, and tests of the composition of the manure, conceptual designs of the three systems were developed. Capital and operating costs of each total system were estimated. These costs were compared to the economic and other benefits of the project. Costs and benefits before and after government incentives (e.g., tax credits, loan guarantees, etc.) were considered.

RESOURCE ASSESSMENT

This subsection presents a description of the Montana Farms operation, biomass characteristics, and the results of our laboratory-scale tests.

Montana Farms Egg Production Operation

The Montana Farms egg farm site is well suited for the development of a biogas production and cogeneration system. The farm is situated on a section of land several miles north of Townsend. The layer houses and feed mill are located at the southwest corner of the section. For disease control reasons, the growing chicken house is located on the southeast corner of the section.

The land on the site slopes to the north. Thus liquid digested manure could be conveyed by gravity to storage lagoons located on Montana Farms property. The residences of adjacent property owners are located at least a mile from the poultry farm.

The Montana Farms egg farm was designed and is operated with energy conservation in mind. The chicken houses are insulated (4 inches of fiberglass) to minimize space heating and cooling requirements. In the summer, the houses are maintained as close to 80°F as possible, and ventilated with outside air. In the winter, the houses are maintained at 60 to 70°F. Buildup of ammonia from the chicken manure in the houses requires introduction of a significant amount of outside air into the houses even in the winter.

Thermostatically controlled fans and propane heaters are used to maintain adequate house ventilation and air temperatures. House lighting is controlled with a time clock to minimize electricity consumption. During the day, lights are turned on 15 minutes per hour which is sufficient to simulate daylight.

Montana Farms owns and uses a 125 kw diesel engine generator and a 25 kw diesel engine generator to supply emergency power to the layer houses and pullet house, respectively.

Montana Farms maintains a fairly constant layer population of 110,000 birds and a growing chicken population of 40,000 birds. The 110,000 layers are housed in three "high-rise" (elevated cages) poultry houses. Every five months the layers in one of the egg production houses are replaced with younger chickens.

Biomass Characteristics

Sizing of any anaerobic digestion system must be based on the quantity and quality of substrate fed to it. During this study, both manure production rates and manure composition were quantified.

Manure Production Rate. Montana Farms personnel established a procedure to collect manure production information in the three lay houses. Plastic lined drawers were mounted directly under two cages of layers in each house. The drawers were situated to collect all the droppings from a known number of hens in each cage. Each day the entire contents of each drawer was weighed and a new plastic sheet was installed for the next period. Each sheet weighs 2 ounces and this was deducted from the total weight.

All measurable factors affecting manure production were and are being recorded. Water meters were purchased and installed in each house during October 1983. Water consumption was a direct influence on the volume and moisture content of the fresh manure.

Manure production data collected to date are analyzed in Table 2-1. As indicated, summer manure production averaged 0.238 pound of wet manure per day per bird. Winter production averaged 0.267 pound per day per bird.

The layers produce manure at a relatively constant rate. However, during a two-week period once every five months, manure production of one-third of the flock is significantly reduced when this portion of the flock is replaced. During this period, manure from growing chickens could be substituted for layer manure.

We have not proposed that manure from growing chickens be normally used for two reasons. First, manure production rates increase significantly over the five-month growing period. A system designed to accommodate any given manure production rate would be inefficient at another rate. Second, manure from growing chickens contains many more feathers than layer manure because of the frequent moulting of growing chickens. Chicken feathers clog piping and pumps and make manure much more difficult to handle.

Table 2-1. Manure Production

Sample date	House number	Brood age, weeks	Average body weight, pounds	House temp. range, deg. F	Feed consump. pcd	Water consump. pcd	Manure prod. pcd
Summer							
7/26/83	1	70	3.62	74-92	.224	-	.205
	2	31	3.29	68-94	.236	-	.262
	3	50	3.36	70-96	.233	-	.226
8/1/83	1	71	3.48	64-90	.229	-	.244
	2	32	3.32	66-92	.236	-	.257
	3	51	3.34	70-94	.229	-	.233
Winter							
10/22/83	1	25	3.23	60-78	.181	.339	.252
	2	44	3.36	60-74	.234	.424	.264
	3	63	3.49	62-78	.241	.407	.26
11/27/83	1	30	3.23	58-74	.209	.381	.229
	2	49	3.45	60-72	.261	.484	.287
	3	68	3.53	60-78	.255	.435	.271
12/23/83	1	34	3.28	52-77	.226	.417	.259
	2	53	3.46	58-77	.269	.407	.293
	3	72	3.52	62-72	.262	.416	.284
Average							
Summer	-	-	-	-	.231	-	.238
Winter	-	-	-	-	.238	.412	.267
Year							.253

Table 2-2. Manure Composition

Type of manure	Date and day sampled	Total solids, percent	Volatile solids, percent	VS/TS, percent	Sodium, mg/kg	Total Kjeldahl nitrogen, mg/kg	Ammonia nitrogen mg/kg	Organic nitrogen mg/kg	pH, units
Fresh	7/25/83 (0)	22.54	15.92	71	697	13300	10500	2800	8
	7/25/83 (0)	21.49	15.96	74	473	12200	10500	1700	7.8
	7/25/83 (0)	25.45	18.74	74	673	13900	10600	3300	8.4
	9/15/83 (52)	28.3	20.9	74	844	16500	8090	8410	6.7
	11/10/83 (96)	30.00	20.4	68	1260	19000	5000	14000	7
	Average of fresh	25.56	18.38	72	789	14980	8938	6042	7.6
Aged	7/25/83 (0)	36.7	15.78	43	1115	12700	11100	1600	8.8
	7/25/83 (0)	41.03	17.98	44	1575	14300	13100	1200	8.6
	7/25/83 (0)	29.77	14.36	48	989	14700	14200	500	8.8
	Average of aged	35.83	16.04	45	1226	13900	12800	1100	8.7

Manure Composition. Manure samples were collected and analyzed for critical constituents at intervals during the data acquisition phase. An analysis of manure composition data collected during this study is presented in Table 2-2.

It is interesting to note that volatile solids as a percent of total solids averaged about 72 percent in fresh manure and about 45 percent in aged manure. This indicates that degradation and loss of volatile solids occurs during aging.

Description of Laboratory-Scale Tests

In this study three reactors were set up to measure the quantity of biogas produced from anaerobic digestion of chicken manure. Experimental variables considered were feed percent, solids mixing, and detention, while other parameters were kept constant. Design criteria are given in Table 2-3.

Table 2-3. Nominal Test Reactor Design Criteria

Reactor	Technology	Percent solids	Mixing sequence	Detention time, days	Loading rate, kg VS/ cu m/day
II	Conventional	7	30/360[a]	20	0.15
III	Innovative	25	30/360[a]	100	0.1
IV	Low	7	None	30	0.1

[a] 30 minutes every 360 minutes.

Bacteria were acclimatized to chicken manure feed by operating a reactor (Reactor I) at low loadings of undiluted manure over a five-month period prior to the start of the laboratory-scale tests. During this time, methanogenic bacteria accustomed to high ammonia levels were allowed to develop.

The initial solids mass in the reactor was obtained by using anaerobically digested sludge from a drying bed at the Bozeman Wastewater Treatment Plant. The bed had not been used for over a year (because disposal of liquid sludge is now practiced), and had about a 5-cm dry drust layer covering the sludge. The gelatinous sludge below the crust was collected for startup of the reactors.

The experimental apparatus for each reactor consisted of an air-tight plastic reactor chamber 22.9 cm high and 14.4 cm in diameter, partially submerged in a water bath kept at 95°F. The biogas left the reactors through a 1/4-inch plastic tube into a reservoir containing a 10 percent sulfuric acid brine solution.

As the biogas was produced, the acidic brine solution was displaced into another container. This displaced liquid volume was then measured and poured back into the reservoir. The maximum head variation in the reservoir was kept below 30 cm.

Finally, to prevent the buildup of fumes during the operation of this experiment, a fume hood was constructed to vent the produced gases outside.

Reactor II. This reactor used conventional technology. Design parameters were based on previous studies using other manure sources for biogas production. The initial mass volume in the reactor was set at 3,000 ml, consisting of 2,160 ml water and 840 ml gelatinous sludge assumed to have a 25 percent solids concentration, for a final percent solids concentration of about 7 percent. In the reactor, a 5.7 cm head space existed above the solids. Mixing in this reactor was accomplished by a flat turbine paddle stirrer similar to those used for bench scale jar tests. The mixing sequence was set for 30 minutes of mixing in a 4-hour duty cycle. The detention time in this reactor was set at 20 days by removing 150 ml of reactor contents and then adding 150 ml of 7 percent manure once a day.

Reactor III. This reactor used innovative technology using undiluted gelatinous sludge for its initial reactor contents. The mass volume was initially set at 3,000 ml of undiluted gelatinous sludge with an initial 25 percent solids concentration which is approximately the same as chicken manure. The reactor contents volume was subsequently reduced to 2,000 ml to prevent plugging of the gas exit port. Mixing was accomplished by a screw auger. The device used to provide mixing in both Reactors II and III was a Phipps and Bird, Inc., Laboratory Stirrer used for laboratory jar tests. The mixing cycle was again 30 minutes in a 360-minute duty cycle. The detention time was set at 100 days by removing 20 ml of reactor solids and then adding 20 ml of undiluted chicken manure each day.

Reactor IV. This reactor used low technology with no mixing and a 7 percent solids concentration identical to Reactor II. The head space was again 5.7 cm. The detention time was set at 30 days by removing 100 ml of reactor solids and adding 100 ml of 7 percent chicken manure daily.

Results of Laboratory-Scale Tests

An analysis of the results of the laboratory-scale tests conducted during this study is presented below.

Biogas Production. Analyses of biogas production data and other results of the laboratory-scale tests are presented in Tables 2-4, 2-5, and 2-6. These analyses recognized that detention times in Reactor II and III were lower than planned at the end of the experiment due to difficulties in measuring sludge withdrawal

Table 2-4. Reactor II Data Analysis

Day	Feed Volume, ml	Feed Weight, grams	Vol. sol, grams	Biogas volume, ml	Bath temp. degree F	Reactor volume, ml	Organic loading, kgVS/cu m per day	Detention time, days	Biogas productn rate, cu m/kgVS added
50	150	44.1	8.26	2721	94	2371	3.48	16	0.33
51	150	44.1	8.26	2665	95	2358	3.50	16	0.32
52	150	44.1	9.22	2675	95	2346	3.93	16	0.29
53	150	44.1	9.22	3315	100	2333	3.95	16	0.36
54	150	44.1	9.22		94	2321	3.97	15	
55	150	44.1	9.22	3152	105	2308	3.99	15	0.34
56	150	44.1	9.22	2070	93	2296	4.02	15	0.22
57	150	44.1	9.22	2138	90	2283	4.04	15	0.23
58	150	44.1	9.22	2345	90	2270	4.06	15	0.25
59	150	44.1	9.22	3864	100	2258	4.08	15	0.42
60	150	44.1	9.22	3129	90	2245	4.11	15	0.34
61	150	44.1	9.22	3052	90	2233	4.13	15	0.33
62	150	44.1	9.22	4740	113	2220	4.15	15	0.51
63	150	44.1	9.22	2500	90	2207	4.18	15	0.27
64	150	44.1	9.22	2345	90	2195	4.20	15	0.25
65	150	44.1	9.22	2370	90	2182	4.22	15	0.26
66	150	44.1	9.22	4928	115	2170	4.25	14	0.53
67	150	44.1	9.22	1935	92	2157	4.27	14	0.21
68	150	44.1	9.22	1885	87	2145	4.30	14	0.20
69	150	44.1	9.22	2688	90	2132	4.32	14	0.29
70	150	44.1	9.22	2521	90	2119	4.35	14	0.27
71	150	44.1	9.22	2980	94	2107	4.38	14	0.32
72	150	44.1	9.22	2980	98	2094	4.40	14	0.32
73	150	44.1	9.22	3567	90	2082	4.43	14	0.39
74	150	44.1	9.22	3270	105	2069	4.46	14	0.35
75	150	44.1	9.22	2793	87	2057	4.48	14	0.30
76	150	44.1	9.22	2554	89	2044	4.51	14	0.28
77	150	44.1	9.22	2800	90	2031	4.54	14	0.30
78	150	44.1	9.22	2603	90	2019	4.57	13	0.28
79	150	44.1	9.22	2670	94	2006	4.60	13	0.29
80	150	44.1	9.22	2665	92	1994	4.62	13	0.29
81	150	44.1	9.22	2495	90	1981	4.65	13	0.27
82	150	44.1	9.22	2574	97	1968	4.68	13	0.28
83	150	44.1	9.22	2185	86	1956	4.71	13	0.24
84	150	44.1	9.22	2260	90	1943	4.74	13	0.25
85	150	44.1	9.22	2250	92	1931	4.78	13	0.24
86	150	44.1	9.22	2204	94	1918	4.81	13	0.24
87	150	44.1	9.22	2250	91	1906	4.84	13	0.24
88	150	44.1	9.22	2514	91	1893	4.87	13	0.27
89	150	44.1	9.22	2685	95	1880	4.90	13	0.29
90	150	44.1	9.22	2750	98	1868	4.94	12	0.30
91	150	44.1	9.22	2070	87	1855	4.97	12	0.22
92	150	44.1	9.22	2060	90	1843	5.00	12	0.22
93	150	44.1	9.22	2030	90	1830	5.04	12	0.22
94	150	44.1	9.22	2310	92	1817	5.07	12	0.25
95	150	44.1	9.22	2190	93	1805	5.11	12	0.24
96	150	44.1	9.22	2615	95	1792	5.14	12	0.28
97	150	44.1	9.22	2775	100	1780	5.18	12	0.30
98	150	44.1	9.22	2710	100	1767	5.22	12	0.29
99	150	44.1	9.22	2890	98	1755	5.25	12	0.31
100	150	44.1	9.22	2460	94	1742	5.29	12	0.27
101	150	44.1	9.22	3590	97	1729	5.33	12	0.39
102	150	44.1	9.22	4000	99	1717	5.37	11	0.43
103	150	44.1	9.22	4175	97	1704	5.41	11	0.45
104	150	44.1	9.22	3765	97	1692	5.45	11	0.41
105	150	44.1	9.22	3050	97	1679	5.49	11	0.33
106	150	44.1	9.22	3380	103	1667	5.53	11	0.37
107	150	44.1	9.22	2500	102	1654	5.57	11	0.27
108	150	44.1	9.00	3150	102	1641	5.48	11	0.35
109	150	44.1	9.00	2725	103	1629	5.53	11	0.30
110	150	44.1	9.00	3000	103	1616	5.57	11	0.33
111	150	44.1	9.00	3000	102	1604	5.61	11	0.33
112	150	44.1	9.00	3173	102	1591	5.66	11	0.35
113	150	44.1	9.00	3580	102	1578	5.70	11	0.40
114	150	44.1	9.00	4000	102	1566	5.75	10	0.44
115	150	44.1	9.00	4000	102	1553	5.79	10	0.44
116	150	44.1	9.00	3740	102	1541	5.84	10	0.42
117	150	44.1	9.00	4000	100	1528	5.89	10	0.44
118	150	44.1	9.00	3300	98	1516	5.94	10	0.37
119	150	44.1	9.00	2750	94	1503	5.99	10	0.31
120	150	44.1	9.00	3650	97	1490	6.04	10	0.41
Average				2896					0.32

Table 2-5. Reactor III Data Analysis

Day	Volume, ml	Feed Weight, grams	Vol. sol, grams	Biogas volume, ml	Bath temp. degree F	Reactor volume, ml	Organic loading, kgVS/cu m per day	Detention time, days	Biogas productn rate, cu m/kgVS added	Biogas productn rate, cu m/kgVS destryd
84	24	21.3	4.45	1240	90	2298	1.94	96	0.28	0.44
85	24	21.3	4.45	1225	92	2302	1.93	96	0.28	0.44
86	24	21.3	4.45	1500	94	2306	1.93	96	0.34	0.54
87	25	21.3	4.45	1226	91	2310	1.93	92	0.28	0.44
88	24	21.3	4.45	1230	91	2315	1.92	96	0.28	0.44
89	24	21.3	4.45	1500	95	2319	1.92	97	0.34	0.54
90	24	21.3	4.45	1395	98	2323	1.92	97	0.31	0.50
91	25	21.3	4.45	1050	87	2327	1.91	93	0.24	0.37
92	24	21.3	4.45	620	90	2332	1.91	97	0.14	0.22
93	24	21.3	4.45	1195	90	2336	1.91	97	0.27	0.43
94	24	21.3	4.45	1260	92	2340	1.90	98	0.28	0.45
95	25	21.3	4.45	1175	93	2344	1.90	94	0.26	0.42
96	24	21.3	4.45	1400	95	2349	1.89	98	0.31	0.50
97	24	21.3	4.45	1600	100	2353	1.89	98	0.36	0.57
98	24	21.3	4.45	1700	100	2357	1.89	98	0.38	0.61
99	25	21.3	4.18	1280	98	2361	1.77	94	0.31	0.49
100	24	21.3	4.18	1000	94	2366	1.77	99	0.24	0.38
101	24	21.3	4.18	1340	97	2370	1.76	99	0.32	0.51
102	24	21.3	4.18	1500	99	2374	1.76	99	0.36	0.57
103	25	21.3	4.18	1355	97	2378	1.76	95	0.32	0.51
104	24	21.3	4.18	1190	97	2383	1.75	99	0.28	0.45
105	24	21.3	4.18	1190	97	2387	1.75	99	0.28	0.45
106	24	21.3	4.18	1700	103	2391	1.75	100	0.41	0.65
107	24	21.3	4.18	1380	102	2395	1.75	100	0.33	0.52
108	25	21.3	4.18	1650	102	2400	1.74	96	0.39	0.63
109	24	21.3	4.18	1500	103	2404	1.74	100	0.36	0.57
110	24	21.3	4.18	1650	103	2408	1.74	100	0.39	0.63
111	24	21.3	4.18	1370	102	2412	1.73	101	0.33	0.52
112	24	21.3	4.18	1425	102	2417	1.73	101	0.34	0.54
113	24	21.3	4.18		102	2421	1.73	101		0.00
114	24	21.3	4.18	1500	102	2425	1.72	101	0.36	0.57
115	24	21.3	4.18	1500	102	2429	1.72	101	0.36	0.57
116	24	21.3	4.18	1500	102	2434	1.72	101	0.36	0.57
117	24	21.3	4.18	1410	100	2438	1.71	102	0.34	0.54
118	24	21.3	4.18	1091	98	2442	1.71	102	0.26	0.41
119	24	21.3	4.18	768	94	2446	1.71	102	0.18	0.29
120	24	21.3	4.18	1050	97	2451	1.71	102	0.25	0.40
Average	24	21.3	2.05	1324				98	0.31	

Table 2-6. Reactor iV Data Analysis

Day	Feed Volume, ml	Feed Weight, grams	Feed Vol. sol, grams	Biogas volume, ml	Bath temp. degree F	Reactor volume, ml	Organic loading, kgVS/cu m per day	Detention time, days	Biogas productn rate, cu m/kgVS added	Biogas productn rate, m/kgVS destryd
50	100	29.4	6.14	1125	94	2659	2.31	27	0.18	0.28
51	100	29.4	6.14	710	95	2652	2.32	27	0.12	0.18
52	100	29.4	6.14	930	95	2645	2.32	26	0.15	0.23
53	100	29.4	6.14	924	100	2638	2.33	26	0.15	0.23
54	100	29.4	6.14	798	94	2631	2.34	26	0.13	0.20
55	100	29.4	6.14	1112	105	2624	2.34	26	0.18	0.27
56	100	29.4	6.14	660	93	2618	2.35	26	0.11	0.16
57	100	29.4	6.14	739	90	2611	2.35	26	0.12	0.18
58	100	29.4	6.14		90	2604	2.36	26		
59	100	29.4	6.14	980	100	2597	2.37	26	0.16	0.24
60	100	29.4	6.14	577	90	2590	2.37	26	0.09	0.14
61	100	29.4	6.14	771	90	2583	2.38	26	0.13	0.19
62	100	29.4	6.14	722	113	2577	2.38	26	0.12	0.18
63	100	29.4	6.14	800	90	2570	2.39	26	0.13	0.20
64	100	29.4	6.14	622	90	2563	2.40	26	0.10	0.15
65	100	29.4	6.14	794	90	2556	2.40	26	0.13	0.20
66	100	29.4	6.14	1435	115	2549	2.41	25	0.23	0.35
67	100	29.4	6.14	960	92	2542	2.42	25	0.16	0.24
68	100	29.4	6.14		87	2536	2.42	25		
69	100	29.4	6.14	567	90	2529	2.43	25	0.09	0.14
70	100	29.4	6.14	500	90	2522	2.44	25	0.08	0.12
71	100	29.4	6.14	465	94	2515	2.44	25	0.08	0.11
72	100	29.4	6.14	745	98	2508	2.45	25	0.12	0.18
73	100	29.4	6.14	726	90	2501	2.46	25	0.12	0.18
74	100	29.4	6.14	1054	105	2495	2.46	25	0.17	0.26
75	100	29.4	6.14	385	87	2488	2.47	25	0.06	0.09
76	100	29.4	6.14		89	2481	2.48	25		
77	100	29.4	6.14	333	90	2474	2.48	25	0.05	0.08
78	100	29.4	6.14	435	90	2467	2.49	25	0.07	0.11
79	100	29.4	6.14	514	94	2460	2.50	25	0.08	0.13
80	100	29.4	6.14	730	92	2454	2.50	25	0.12	0.18
81	100	29.4	6.14	695	90	2447	2.51	24	0.11	0.17
82	100	29.4	6.14	550	97	2440	2.52	24	0.09	0.14
83	100	29.4	6.14	521	86	2433	2.53	24	0.08	0.13
84	100	29.4	6.14	378	90	2426	2.53	24	0.06	0.09
85	100	29.4	6.14		92	2419	2.54	24		
86	100	29.4	6.14	506	94	2413	2.55	24	0.08	0.12
87	100	29.4	6.14	540	91	2406	2.55	24	0.09	0.13
88	100	29.4	6.14	621	91	2399	2.56	24	0.10	0.15
89	100	29.4	6.14	980	95	2392	2.57	24	0.16	0.24
90	100	29.4	6.14	833	98	2385	2.58	24	0.14	0.21
91	100	29.4	6.14	575	87	2378	2.58	24	0.09	0.14
92	100	29.4	6.14	625	90	2372	2.59	24	0.10	0.15
93	100	29.4	6.14	650	90	2365	2.60	24	0.11	0.16
94	100	29.4	6.14	555	92	2358	2.61	24	0.09	0.14
95	100	29.4	6.00	540	93	2351	2.55	24	0.09	0.14
96	100	29.4	6.00	805	95	2344	2.56	23	0.13	0.20
97	100	29.4	6.00	880	100	2337	2.57	23	0.15	0.22
98	100	29.4	6.00	780	100	2331	2.57	23	0.13	0.20
99	100	29.4	6.00	1125	98	2324	2.58	23	0.19	0.28
100	100	29.4	6.00	940	94	2317	2.59	23	0.16	0.24
101	100	29.4	6.00	1115	97	2310	2.60	23	0.19	0.28
102	100	29.4	6.00	1205	99	2303	2.60	23	0.20	0.30
103	100	29.4	6.00	1305	97	2297	2.61	23	0.22	0.33
104	100	29.4	6.00	615	97	2290	2.62	23	0.10	0.16
105	100	29.4	6.00	1570	97	2283	2.63	23	0.26	0.40
106	100	29.4	6.00	1170	103	2276	2.64	23	0.20	0.30
107	100	29.4	6.00	1315	102	2269	2.64	23	0.22	0.33
108	100	29.4	6.00	1830	102	2262	2.65	23	0.31	0.46
109	100	29.4	6.00	1770	103	2256	2.66	23	0.30	0.45
110	100	29.4	6.00	2000	103	2249	2.67	22	0.33	0.51
111	100	29.4	6.00	1905	102	2242	2.68	22	0.32	0.48
112	100	29.4	6.00	2000	102	2235	2.68	22	0.33	0.51
113	100	29.4	6.00	2100	102	2228	2.69	22	0.35	0.53
114	100	29.4	6.00	2175	102	2221	2.70	22	0.36	0.55
115	100	29.4	6.00	2145	102	2215	2.71	22	0.36	0.54
116	100	29.4	6.00	1500	102	2208	2.72	22	0.25	0.38
117	100	29.4	6.00	1655	100	2201	2.73	22	0.28	0.42
118	100	29.4	6.00	1600	98	2194	2.73	22	0.27	0.40
119	100	29.4	6.00	1500	94	2187	2.74	22	0.25	0.38
120	100	29.4	6.00	1775	97	2180	2.75	22	0.30	0.45
Average				992			2.52		0.16	

volumes. It was apparent that the effectiveness of the bacteria culture in Reactor II in destroying volatile solids declined as detention times declined, as one would expect. Both reactors operated stably at the shorter detention times. It should be noted that the biogas volumes in Tables 2-4, 2-5, and 2-6 should be reduced by 13 percent to reflect the volumes under standard conditions (68°F, one atmosphere, and dry).

Biogas Composition. During the last month of the tests, the biogas produced by each reactor was tested for methane content. These data are analyzed in Table 2-7.

Table 2-7. Biogas Methane Content

	Methane content, percent		
Date	Reactor II	Reactor III	Reactor IV
11/8/83	60	50	50
11/10/83	60	50	55
11/12/83	55	51	55
11/13/83	56	47	56
11/15/83	56	46	55
11/17/83	56	46	53
11/20/83	58	49	56
Average	57	48	54

Ammonia Toxicity. Ammonia-nitrogen is known to be toxic to methanogenic bacteria. For this reason, both feed and reactor content levels were monitored as indicated in Table 2-8.

Ammonia-nitrogen concentrations reached relatively high concentrations in all reactors. Concentrations in Reactor III reached 11,000 mg/l. Values reported in the literature were as follows:

Investigator	Ammonia-nitrogen concentration, mg/l
Hart[1]	2,900 - 4,100
Gramms et al.[2]	1,020 - 3,150
Converse et al.[3]	7,055 - 8,062
Rocky et al.[4]	8,700 - 11,400

Thus, the concentrations measured in this study exceeded most of those reported in the literature.

Table 2-8. Composition of Reactor Contents

Reactor	Date and day sampled	Total solids, percent	Volatile solids, percent	Sodium, mg/kg	Total Kjeldahl nitrogen, mg/kg	Ammonia nitogen, mg/kg	Organic nitrogen, mg/kg	pH, units
II	9/15/83 (52)	2.67	1.76	383	4370	3420	950	7.3
	10/25/83 (94)	4.09	2.85	188	4500	4400		7.8
	11/22/83 (120)	5.38	3.39	330	6900	5200	1700	8.4
	Average for II	4.05	2.67	300	5257	4340	1325	7.80
III	9/15/83 (52)	13.4	8.17	317	9330	5830	3500	8.5
	10/25/83 (94)	9.67	6.28	165	8000	7400	600	8.3
	11/22/83 (120)	11.8	7.48	540	13000	11000	2000	8.7
	Average for III	11.6	7.31	341	10110	8077	2033	8.5
IV	9/15/83 (52)	2.16	1.38	250	4160	2950	1210	7
	10/25/83 (94)	3.84	2.68	164	4600	3800	800	7.7
	Average for IV	3.00	2.03	207	4380	3375	1005	7.4

McCarty[5] showed that ammonia nitrogen toxicity is related to free ammonia concentration. The amount of free ammonia that exists in water at 35°C is a function of the ammonium concentration and the hydrogen ion concentration (pH) as follows:

$$(NH_3) = 1.13 \times 10^{-9} (NH_4^+)/(H^+)$$

Thus, the higher the pH, the lower the ammonium ion concentration required to produce a given free ammonia concentration. At a temperature of 35°C and a pH of 7, none of the ammonia would exist as free ammonia. At a pH of 8.5, some 30 percent of it would.

Both reactors II and III were operating at relatively high pH levels near the end of the tests. The calculated free ammonia-nitrogen concentrations in these reactors are as follows:

Reactor	pH	Free ammonia-nitrogen concentration, mg/l
II	8.4	1,300
III	8.7	4,000

The literature does not reveal any other digester operated at anywhere near these free ammonia levels that did not fail during the test. The success of this test illustrates the ability of methanogenic bacteria to become acclimatized to higher free ammonia levels than had been considered possible in the past.

Reduction of these high free ammonia levels could be achieved by adding an acid, such as hydrochloric or sulfuric acid. Perhaps better would be the addition of a salt, such as calcium chloride, which would reduce the pH sufficiently without danger of decreasing it too far. The design of a high solids reactor should definitely incorporate this capability.

It is interesting to note that previous investigators have measured the impact of ammonia concentrations on the process by noting changes in only the volume of biogas produced--not in its composition. In this experiment, only the methane content and not the amount of gas produced per pound of volatile solids added was reduced by high solids, and, hence, high ammonia concentrations.

Salt Inhibition. High concentrations of sodium salts can inhibit the anaerobic digestion process. A significant increase in gas production has been reported when sodium concentrations exceed 3,900 mg/l. At no time during these tests did sodium concentrations reach even 15 percent of this level. Therefore, sodium inhibition of the process was very unlikely.

Summary. Based on the above, we believe that the following biogas production rates could be achieved with the reactors operating within reasonable ranges of temperature, detention time, and pH:

Reactor	Technology	Detention time, days	Biogas production rate,[a] cu m/kg VS added	
			Average	Range
II	Conventional	10	0.40	0.35-0.45
		15	0.45	0.40-0.50
		20 (est.)	0.50	0.45-0.55
III	Innovative	100	0.33	0.30-0.36
IV	Low	20	0.33	0.30-0.36
		30 (est.)	0.36	0.33-0.39

[a]At standard conditions of temperature and pressure.

Figure 2-1 illustrates the increase in biogas production associated with increased detention time. Even with the use of conventional technology, adding slightly less dilution water to the manure would increase its detention time in the digester and increase biogas production.

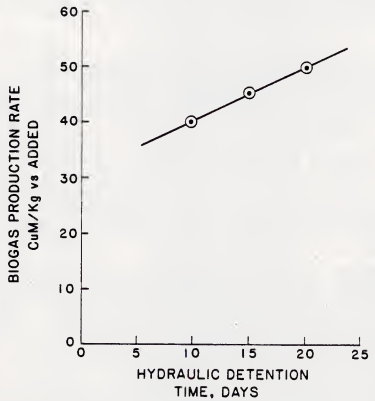


Figure 2-1. Biogas Production

An estimate of the energy production rates associted with each technology is presented in Table 2-9. These results indicate that mixing can significantly increase the gross energy production rate of a system.

Table 2-9. Estimated Energy Production Rates

Technology detention time, days	Manure loading, kg/day: Total solids	Manure loading, kg/day: Volatile solids	Average biogas production rate: Cubic meters per day	Average biogas production rate: Million Btu per day
Conventional				
10	3,200	2,300	1,060	21.3
15	3,200	2,300	1,200	24.0
20 (est.)	3,200	2,300	1,200	26.6
Innovative				
100	3,200	2,300	870	14.7[a]
Low				
20	3,200	2,300	870	16.7
30 (est.)	3,200	2,300	950	18.2

[a]This value might be increased with adequate pH control of reactor contents.

ENERGY USE

Two forms of energy are used by the Montana Farms operation: electricity and propane. An analysis of these energy requirements is presented below.

Electrical Energy Requirements

Electrical energy is used for ventilation and lighting of the layer and brooder houses, as well as for egg and feed conveying, feed grinding, and water pumping. Total annual electrical energy demands for the last six years are presented in Table 2-10. Over the last three years, total annual electrical energy use has averaged over 600,000 kilowatt hours per year.

Data in Table 2-11 illustrate monthly variations in electrical energy use during a typical year (1982). In general, higher electrical energy demands occur during the warmer months, when more ventilation is needed.

Table 2-10. Total Annual Electrical Energy Demand

Year	Energy demand, kilowatt hours[a]				
	Lay houses and egg processing	Brooder house	Feed mill	Well pump	Total
1977	420,720	101,210	79,360	13,260	614,550
1978	511,040	109,170	152,640	23,001	795,851
1979	413,664	108,740	111,360	22,819	656,583
1980	451,999	52,760	96,000	10,570	610,330
1981	429,880	82,620	80,320	17,290	609,310
1982	415,440	89,910	97,880	12,943	616,173
Average	440,160	90,740	102,930	16,650	650,480

[a]During this period, average annual energy demands were impacted by an experiment in milling grain for off-farm sale and loss of all birds due to PCB poisoning.

Table 2-11. 1982 Monthly Electrical Energy Demand

Month	Energy demand, kilowatt hours				
	Lay houses and egg processing	Brooder house	Feed mill	Well pump	Total
Jan	38,040	7,320	19,520	70	77,823
Feb	27,520	5,670	8,680	404	42,234
Mar	36,760	8,090	14,720	552	60,122
Apr	40,920	10,010	12,160	2,604	63,090
May	19,640	3,900	3,200	1,186	27,926
Jun	41,640	10,090	4,800	548	57,078
Jul	34,040	8,000	2,240[a]	1,729	46,009
Aug	45,680	11,380	2,240[a]	797	60,097
Sep	38,080	6,740	2,880	630	48,330
Oct	36,040	6,140	6,080	878	49,138
Nov	27,120	6,260	6,080	545	40,055
Dec	29,960	6,220	15,360	950	52,490
Total	415,440	89,910	97,880	12,943	616,173

[a]Estimated; July was 6,720 and August was -2,240.

Hourly electrical energy use data were also collected. An analysis of data collected during a typical month (October, 1983) is presented in Table 2-12. Minimum power demands averaged about 35 kilowatts (kw) during October, while the average demand was about 55 kw and the peak demand was about 100 kw.

Table 2-12. Layer Houses--Daily Electrical Energy Demand

Date	Day	Daily energy use, kwh	Daily demand, kw		
			Average	Maximum	Minimum
10/11/83	Tuesday	1,357	57	85	37
10/12/83	Wednesday	1,375	57	89	35
10/13/83	Thursday	1,379	57	89	35
10/14/83	Friday	1,331	55	90	36
10/15/83	Saturday	1,322	55	89	36
10/16/83	Sunday	1,282	53	89	37
10/17/83	Monday	1,329	55	91	35
10/18/83	Tuesday	1,323	55	83	36
10/19/83	Wednesday	1,320	55	89	38
10/20/83	Thursday	1,308	55	90	36
10/21/83	Friday	1,328	55	89	36
10/22/83	Saturday	1,423	59	103	36
10/23/83	Sunday	1,316	55	89	39
10/24/83	Monday	1,290	54	82	36
10/25/83	Tuesday	1,382	57	90	36
10/26/83	Wednesday	1,434	60	100	35
10/27/83	Thursday	1,474	61	101	38
10/28/83	Friday	1,318	55	86	34
10/29/83	Saturday	1,333	56	92	35
10/30/83	Sunday	1,411	58	100	35
10/31/83	Monday	1,530	63	100	39
11/1/83	Tuesday	1,411	59	98	36
11/2/83	Wednesday	1,343	56	96	36
11/3/83	Thursday	1,395	58	97	37
11/4/83	Friday	1,369	57	95	37
11/5/83	Saturday	1,285	54	95	36
11/6/83	Sunday	1,364	57	95	36
11/7/83	Monday	1,193	50	85	32
11/8/83	Tuesday	1,167	49	79	31
11/9/83	Wednesday	1,134	47	79	31

A plot of samples of several months of data collected with a recording meter on the circuits supplying (1) the layer houses and egg room, and (2) the feed mill, is presented on Figure 2-2. The plot clearly shows that operation of the feed mill exerts a large power demand during the afternoon and evening. Because layer house and egg room energy demands are fairly consistent, it does not

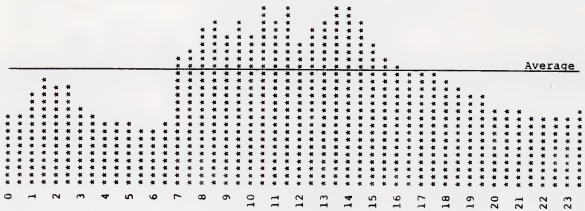


Figure 2-2. Hourly Electrical Demands

appear that scheduling feed mill operation during the night shift would significantly reduce peak power demands. Furthermore, it is unlikely that savings in demand charges would offset increases in labor costs due to night shift operation.

Montana Farms has instituted some operational changes designed to reduce peak power demand, thereby making on-site power generation more cost effective. An example of these changes is adjustment of automatic time clocks to stagger the intermittent lighting of the lay houses.

Propane Consumption

Propane is used for space heating of the three layer houses, the brooder house, and the egg processing area. It is also used for heating of water used in egg processing.

Total annual propane consumption, broken out by layer houses, brooder house, and egg processing categories, is presented in Table 2-13. Annual propane consumption for space heating varies withoutside air temperature. Egg processing propane consumption has been reduced significantly in recent years.

Table 2-13. Total Annual Propane Consumption

Year	Propane consumption, gallons			
	Layer houses	Brooder house	Residences[a]	Total
1977	16,112	8,717	10,277	35,106
1978	16,451	16,802	11,667	44,920
1978	25,604	10,375	8,232	44,211
1980	20,485	9,333	4,090	33,908
1981	15,356	13,673	3,745	29,404
1982	21,967	13,392	5,032	40,391
Average	19,329	12,048	6,174	37,990

[a]Residence space heating propane use was reduced in 1980 when wood stoves were installed.

Propane consumption by month for a typical year (1982) is presented in Table 2-14. Propane use for heating the layer houses and brooder house reaches a minimum during July, August, and September. The propane consumption data presented in Table 2-9 reflect purchases and not actual use, and should, therefore, be considered approximate.

Table 2-14. 1982 Monthly Propane Consumption

Month	Propane consumption, gallons			
	Layer houses	Brooder house	Residences[a]	Total
Jan	5,070	1,155	801	7,026
Feb	1,400	0	240	1,640
Mar	2,375	2,270	4122	5,057
Apr	1,911	1,780	295	3,986
May	520	120	250	890
Jun	900	535	325	1,760
Jul	550	0	142	693
Aug	0	965	0	965
Sep	600	0	0	600
Oct	1,775	995	750	3,520
Nov	3,115	775	456	7,866
Dec	3,760	4,797	1,360	9,917
Total	21,976	13,392	5,032	40,400
Average	1,831	1,116	419	3,366

Taking an average over the period July through September, 1982, some 1,100 gallons per month is the minimum average propane use. This represents an average heat demand of abaout 100,000 Btus per hour. Under "typical" conditions, this amount of heat demand could be used as a sink for the net waste recoverable waste heat from a biogas cogeneration system that produces about 50 kw of electrical power. Thus there is a reasonably good match between electrical power requirements and minimum heat demands at this facility. Daily storage of heat, in the form of hot water storage, for example, may be required to exactly match waste heat generation and heat demands.

DEVELOPMENT OF SYSTEM OPTIONS

This section presents screening level evaluations of system components and a description of each of the optimized systems.

Screening-Level Evaluations

Screening-level evaluations of system components were conducted to ensure that each of the basic system options was optimally configured.

Handling of Solid vs. Liquid Manure. Raw manure can be conveyed to the anaerobic digestion system in either solid or liquid form. With either method, up to 3.4 dry tons per day of manure will have to be transported. The manure handling problem is really two problems. The first is to collect the manure and transport it to the digester area. The second is to feed it to the digester.

With solid manure handling, several options are available for manure collection. One option is to install a chain and flight scraper system on a hard surface beneath the cages. This system would drag the manure to a U-trough screw conveyer system along the ends of the houses which would convey the manure to the tank feeding system. This type of system would be too expensive to install in Montana Farms' 500-foot long high-rise chicken houses.

Under a second option, a small skid steer loader or crawler loader would be used to scoop up the manure and convey it to the digester. Loaders are available with roll-proof canopies that could operate within the 6-foot high space beneath the cages. Slanted shelves could be used to direct manure away from the series of posts that are located under every other set of cages. The boards that tilt toward the outside rows should extend under 1/3 of the fourth cage in from each outside wall to ensure that each row contains 1/3 of the manure output of the house, as indicated in Figure 2-1.

With this option, manure would accumulate on the floor of the manure pit, in three 12- to 14-foot wide rows. With daily manure collection, it would be necessary to provide a paved surface (with

a curb on each side) upon which the manure would fall. A thin layer of manure could not be easily removed from an unpaved surface. With less frequent manure collection, say on the order of weeks or months between collection, an unpaved surface would suffice as a thicker layer of manure would accumulate.

For example, if one 500-foot row of manure were collected every day, nine days would pass between collections. Each collection would produce an amount of manure equivalent to one day of manure production. Only about an inch of manure would accumulate on the floor of the pit over a nine-day period.

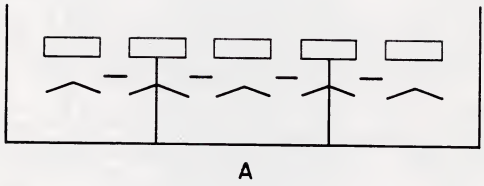
A third option would be to install a dropping board system similar to that used by the Cherry Lane Farms operation in Three Forks. With this system, slanted dropping boards are installed under each set of cages. A litter cart equipped with dozer blades that extend outward from each side of a hopper and slanted at the same angle as the dropping boards is used to collect the manure. At Montana Farms, such a system could be constructed as shown on Figure 2-3. The chicken houses at Cherry Lane Farms each hold 22,000 to 26,000 chickens and can be cleaned in 45 minutes per day using this method. This method is only appropriate for frequent manure collection (i.e. every day or every other day).

Liquid manure collection would involve installation of an inclined concrete trough flushing system to convey diluted manure to the digester system. An elevated flushing water storage tank would be constructed to provide a sufficient volume of water to flush daily accumulation of manure to the end of the buildings. Liquid manure handling has the following disadvantages: (1) too much dilution of the manure would occur; (2) the manure would lose heat to the flushing water, heat that could be conserved to reduce anaerobic digestion energy demands; and (3) the design of the 500-foot long high-rise chicken houses does not lend itself to this type of system.

Based on the above evaluation, we believe that solid manure collection appears most promising. More frequent manure collection favors a dropping board system, while infrequent manure collection would favor the use of a skid steer loader system, as paving of the floor of the manure pits would not be necessary.

Feeding solid manure (25 to 35 percent total solids) to the digester would be more difficult than feeding a slurry. With a conventional feeding system, manure is transported to a mixing tank where liquid is mixed with the solid manure and then the slurry is pumped through a heat exchanger into the digester.

The mixing tank could be sized to allow filling once a day and then continuous automatic feeding of the digester over the entire day. This procedure would allow more uniform biogas production over the day (eliminating the cost of a floating cover for the digester



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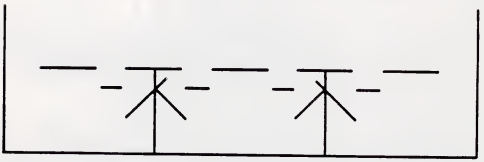

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Figure 2-3. The Manure Collection Systems

and/or biogas storage) and would minimize digester upsets during feeding. Alternatively, an agitator/mixer with a hopper large enough to contain and dilute the amount of manure delivered by a front end loader could be used. Feeding of the digester could occur continuously over the time the manure was delivered to the mixer.

Feeding solid manure would involve use of a live center feed hopper. The feed hopper would have sufficient storage volume (500 cubic feet) to allow continuous metering of the manure to the mixing equipment using a twin screw feeder. In the mixer, digester contents (at 12 percent total solids) would be used to dilute the mixture to 15 percent solids, the effective limit for pumping. At a manure production rate of 460 cubic feet per day (2.4 gpm), about 8 gpm of digester contents would be required for dilution. Digester contents, and not supernatant, would be used to prevent buildup of ammonia in the digester.

Mixing could occur in a mixing tank of similar design to that used with a conventional system. Alternatively, an agitator mixer could be used. The downstream grinder and sludge pump would be oversized to accommodate the total mixed flow. Level controls on the mixing tank or mixer would prevent overflow.

Digestion of Aged vs. Fresh Manure. During one year of on-site storage, the manure loses about 13 percent of its volatile matter (16.04/18.38 = 0.87) and about 28 percent of its moisture content (25.56/35.83 = 0.71). It is also likely that the remaining volatile matter is less biodegradable.[1] Thus anaerobic digestion of aged manure would produce less biogas than fresh manure. On the other hand, as the manure ages, it undergoes exothermic oxidation, i.e., composting. For this reason, aged manure is warmer than fresh manure (by about 8°C). Using aged manure as digester feed could reduce the energy demands of the anaerobic digestion process.

More than enough manure is available to produce sufficient biogas to fuel an engine generator large enough to supply Montana Farms' base energy demands. For this reason and because volatile matter losses during aging are relatively minor, we believe that some aging of the manure is acceptable. As was noted earlier, nine days of aging would occur if manure in one of the nine rows of manure were collected each day. If, each day, one-quarter of a row (i.e., 125 lineal feet) were collected (on a 36-day cycle), the four inches of accumulated manure would have begun to compost (i.e., heat up) prior to collection. Problems that would have to be overcome to implement this option include:

1. The loader would either have to have sufficient ground clearance to clear the accumulated manure or a mid-length manure pit entry door would have to be added to each house.

2. A means would have to be found to prevent excessive building heat loss during the winter during the 30 to 40 trips needed daily to remove the manure.

Skid steer loaders have a ground clearance of 6-1/2 inches, and would therefore solve the first problem. The second problem could be at least partially solved by adding some sort of air lock to each manure pit entry door.

Allowing the manure to accumulate for 30 to 40 days prior to collection would solve two problems. First, expense of paving the floor of the manure pit could be eliminated, saving over $40,000 in materials costs alone. Second, heating of the manure on the floor of the manure pit would probably occur, reducing manure heating requirements.

The problem of heat loss from the houses during manure collection could also be reduced and disturbance to the chickens minimized by removing all of the manure from each house every 6 weeks and feeding the digester from the stockpile over the two-week period until the next house is emptied. These problems could be completely eliminated by removing the manure as it is now--on a five-month cycle when one of the houses is empty during the replacement of the older chickens with younger birds. With this method, manure could be stockpiled on-site and digester feed could be slowly increased or decreased (within reasonable limits) to increase system output when it was needed. The advantages of this procedure (less heat loss and no decrease in egg production due to disturbance) are not possible to quantify, but are significant enough to warrant testing the concept, recognizing that a decrease in biogas production will result.

Ebullient Cooling vs. Hot Water Cooling. One of the major problems associated with recovering heat from digester gas is corrosion caused by sulfur dioxide and sulfur trioxide, the combustion products of hydrogen sulfide gas. If the exhaust gas temperature is allowed to drop below its dewpoint, the condensate which forms is acidic as a result of absorbing sulfur oxides. The acidic condensate is corrosive to metallic elements of exhaust-carrying systems.

There are two ways to alleviate this problem. The first is to remove the hydrogen sulfide from the gas before combustion. This can be accomplished by passing the gas through a mass of iron fibers or by scrubbing the sulfur oxides out of the gas stream with water.

A simpler way to prevent corrosion is to maintain the exhaust gas at temperatures considerably greater than its dewpoint to prevent condensation. This generally requires that the water temperature of any boiler or engine using unscrubbed gas be at least 212°F (100°C). Also, stack gas temperatures should not be allowed to drop below 350 to 400°F (177 to 204°C). Use of unscrubbed digester gas is preferred. Equipment fueled by unscrubbed digester gas cannot be used in intermittent service, since condensation will occur each time the unit is shut down. Shutdown must be minimized. Similarly, the equipment must be designed so that even when operated at its lowest loadings, exhaust gas temperatures are sufficiently high to prevent condensation.

Exhaust temperatures can be maintained sufficiently high with both ebullient (vapor-phase) cooling and hot water cooling of the prime mover. For all the engine sizes considered during this study, only hot water-cooled engines were readily available. Hot water cooling was, therefore, incorporated into all of the system options studied.

Direct Burning vs. Cogeneration. A biogas utilization system is optimized when the biogas is put to its highest use. The highest use is that use which will minimize that cost of energy used on-site or maximize the revenue from off-site sale of energy. Both heat and electricity are used on-site in this instance, and, therefore, savings associated with direct burning vs. savings associated with cogeneration should be compared. Electricity could be wheeled through the Vigilante Electric Cooperative's system, and, therefore, that option should be evaluated. Although federal tax credits are available for sale of biogas to non-related parties (worth about $0.068 per 100,000 Btu), this option is not practical for Montana Farms.

Propane costs Montana Farms $0.585 per gallon, or $0.694 per 100,000 Btu. If biogas were burned for its heat value at the same efficiency (80 percent) and cost as propane, it would save about $0.87 per 100,000 Btu of useful energy produced. This assumes that the biogas is required as it is produced and that no storage costs are involved. This is true for egg washing heat requirements but not for space heating requirements, which are seasonal in nature.

Cogeneration equipment under study herein requires about 12,200 Btu of biogas to produce 1 kwh of electricity. In addition, about 53 percent of the heat value of the biogas used as fuel is available as useful heat in the cooling water. If biogas is used in this mode, electricity production would save Montana Farms $0.38 per 100,000 Btu of biogas used considering energy charges only (and not demand charges). To this can be added the value of the heat produced (assuming it can be used as it is produced), which has a value of $0.46 per 100,000 Btu of biogas used (0.53 x $0.87). The total value of the biogas is then $0.84 per 100,000 Btu.

If electricity is produced continuously at a rate that exceeds the minimum rate of electricity consumption at Montana Farms (about 40 kw), then the electricity only has value if it can be sold. Under a 10-year levelized power purchase contract with Montana Power Company, electricity so produced would be worth $0.0468/kwh. With an assumed wheeling charge of $0.005/kwh, the net value of biogas used in this mode would be $0.34 per 100,000 Btu.

It is apparent, then, that with system options that can produce more than about 40 kw, a combination of cogeneration with on-site use and off-site sale should be selected. With this combination, no storage of either electricity or biogas is required. Engine heat should first be used for heating the water required for egg washing

water (about 3 million Btu/day, average). During the space heating season, September through June, air heated by the waste heat radiator should be directed into the layer houses to reduce space heating (and ventilation) requirements. This could be accomplished by locating the radiator between two of the houses and directing the heated air through insulated ducts into the houses. During the summer, the hot air could be directed into compost piles to aid in manure drying.

If surplus biogas is available, it should be used to fuel the existing propane air heating units. Additional burners could be added to each unit (at a cost of $170 per unit) that would allow both propane and biogas to be burned. Alternatively, new fan coil units could be installed to burn the biogas (at a cost of $540 per unit). Four such units would be required per layer house. Piping biogas to the layer houses could cost another $6,200--half of that cost being materials.

Wheeling of electricity through Vigilante Electric Cooperative to Montana Power Company would require negotiation of contracts with both organizations. Discussions with Vigilante management indicate that Vigilante would require the following of any small power producer connected to its system:

1. Adequate liability insurance.

2. Adequate interface and metering equipment.

3. Reimbursement for the cost of oversizing power lines, if required.

The Public Service Commission regulates Montana Power Company power purchase agreements, conditions, and rates. The Federal Energy Regulatory Commission regulates the Vigilante Electric Cooperative.

Stabilized Manure Land Disposal vs. Sale. After anaerobic digestion, a relatively large volume of dilute (3 to 12 percent total solids) stabilized manure will require disposal. The stabilized manure will be high in nutrients as indicated below:

	Concentration	
Nutrient	Percent	Pound per ton dry solids
Nitrogen	0.5 - 1.0	10-20
Phosphorus	0.23 - 0.35	5-7

Although these concentrations are almost an order of magnitude less than those available in commercial fertilizers, the manure would make an excellent soil conditioner or potting mix.

At present, Montana Farms disposes of unstabilized, aged manure in solid form on local farms using a dry manure spreader. As the stabilized manure will leave the digester in a liquid (slurry) form, either a new means of spreading the liquid manure or a means of drying the manure will have to be used.

If liquid manure spreading is implemented, from 8,000 to 12,000 gallons per day of liquid sludge would have to be handled. However, because sludge can be applied only at the beginning of the growing season, storage of the liquid sludge during 10 or more months of the year would be required. A dredge (costing over $100,000) or some other means of removing the liquid sludge from the lagoon would be needed.

We believe that disposing of the stabilized manure in liquid form would be too expensive. We therefore recommend that the manure be dried prior to transport off-site, either for disposal or sale. The two easiest methods for drying sludge are drying lagoons and drying beds.

With drying lagoons, 6 inches to 1 foot of anaerobically digested sludge is applied to a lagoon and then allowed to dry by decanting supernatant after a week or so and then by evaporation. With drying beds, the liquid in the sludge also drains downward through a layer of sand over a layer of gravel, kept dewatered by underdrain piping.

Because drying lagoons are simple earthen structures, they are less expensive to build. An additional advantage is that less land area is required. For these reasons, drying lagoons are incorporated into the system options evaluated in this report.

At Montana Farms, up to 1,600 cubic feet per day of stabilized manure will require drying. This amount of manure would cover a 20- by 80-foot area of lagoon 1 foot deep. Drying lagoons have been successfully used as far north as Chicago and could be used in Townsend. In Chicago, a 30-day loading cycle is used; that is, 30 lagoons, each large enough to accept one day's digester output, are rotated. Using this same rotation at Montana Farms, an 80-foot by 600-foot lagoon area would be required. After a year of drying, dried manure (30 to 35 percent solids) could be removed with a skip steer loader. Lagoon depth is a function of drying rate and of the amount of storage it is to provide. To provide eight months of storage, up to 3 feet of depth could be required.

During the summer months, dried manure could be disposed of on local farms as it is now, or it could be composted, packaged, and sold. Composting of the manure would further stabilize the organic material in the manure, kill any seeds remaining in the manure, and further dry the manure. Composting is an aerobic thermophilic process. Air must be supplied and heat is generated.

Even after drying in a drying lagoon or drying bed, the dried manure would still be too wet to satisfy optimum composting conditions. The moisture content could be further reduced by blending a dry bulking material with the manure. With a 30 percent total solids dried manure, one volume of wood chips (or some other bulking agent such as sawdust, straw, etc.) would have to be added to produce a mixture with an overall moisture content of less than 60 percent.

In the United States, the windrow and aerated static pile composting processes have been used almost exclusively for composting manures. In the windrow method, oxygen is drawn into the pile by natural convection and by turning, whereas in the static pile method, aeration is induced by forced air circulation. Windrow composting requires the least initial investment and is generally the process of choice if land and a tractor to turn the windrows are available. The width of a typical windrow is 15 feet and the height is 3 to 7 feet. Each windrow must be turned two or three times per day for the first five days to mix the material completely and then once a day for about 30 days. The compost can be screened at the end of the composting period to recover the bulking agent if a relatively large bulking agent, such as wood chips, is used.

Bulk composted manure can be produced for $50 to $100 per dry ton of manure, depending on the cost and availability of bulking agents. The cost of bagging the manure and transport to the point of sale must be added to this cost. If about 20 percent of the weight of finished compost is dry manure solids, and unscreened compost has a density of 100 lb/cu yd, then, at $100 per dry ton of manure, compost could be produced for about $0.40 per cubic foot. Composted chicken manure retails for abaout $2 per cubic foot. If a low cost bulking agent, a market for the compost, and a low-cost means of transport could be found, the benefit of composting could outweigh its cost. Pilot testing of the concept on a small scale could be accomplished at relatively low cost to confirm the economics of the process. Even with a process failure, the compost would be more stable than the digested manure.

Because full-scale composting of dried manure would introduce additional capital cost and add risk to the project, we do not recommend its incorporation into the system options given detailed study. Composting could be implemented under any of the action alternatives at a later date.

Description of Systems

Based on the results of laboratory testing of three anaerobic digestion technologies and the findings of screening level evaluations of system components, three biogas producing system options have been formulated. Each system option includes manure collection, anaerobic digestion, cogeneration of electricity and thermal energy, and manure disposal and/or reuse.

System Option 1: Conventional Technology

With System Option 1, manure would be collected and transported to the digester feeding system using a skid steer loader. The feeding system would dilute the manure to about 7 percent solids prior to feeding to the anaerobic digester.

The conventional digestion process requires that strict environmental conditions be maintained for the anaerobic bacteria. The organisms grow optimally at a digester temperature of about 85°F, with the pH in the range from 6.6 to 7.6. In addition, the concentration of inhibitory or toxic materials must be below critical levels. Of particular concern for this project is the inhibitory effects of high ammonia concentrations.

Given the proper environmental conditions, the anaerobic bacteria will digest the chicken manure and produce biogas, a mixture of approximately 60 percent methane and 40 percent carbon dioxide, with small amounts of other gases. The digestion process destroys about 50 percent of the volatile matter in the manure. A substantial portion of the nitrogen is concurrently solubilized. An internal combustion engine would burn the digester gas and drive a generator to produce electricity for on-site uses. The exhaust and cooling heat produced by the engine would be recovered and used for maintaining the digester tank temperature and heating egg washing water. Excess gas would also be used to replace propane now used to heat the laying house.

Other components of the process include a mixing tank for combining water with manure solids, a fan cooled radiator for wasting engine heat when heat production exceeds demand, and a hot water storage tank for egg washing water.

The specific design criteria and assumptions concerning the conventional system option is outlined in the following paragraphs. Figure 2-4 is a schematic of the system shwing the energy and mass flow rates for each process stream. A layout of the digestion/ cogeneration facilities is presented on Figure 2-5.

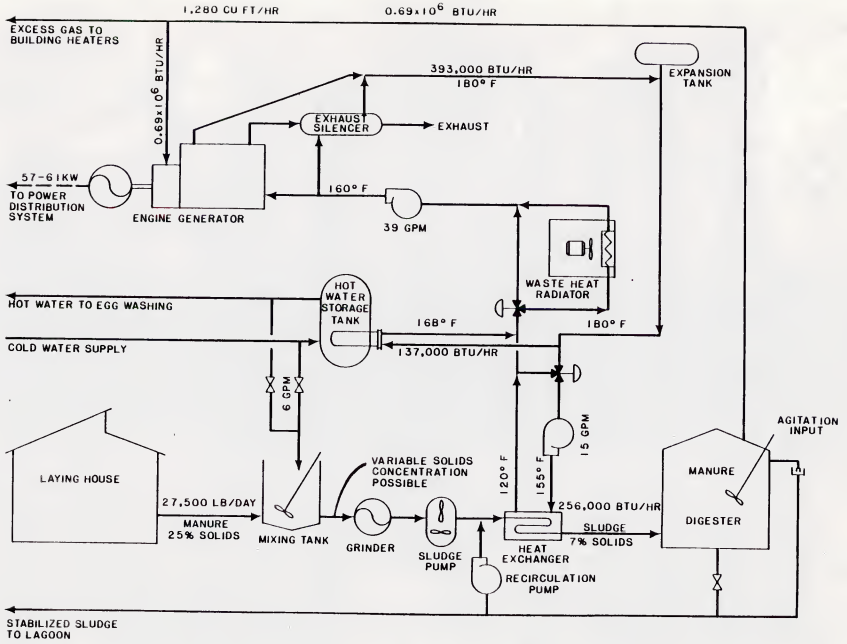

Figure 2-4. Schematic Flow Diagram and Energy Balance: System Option 1

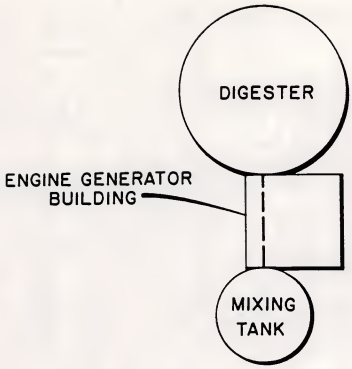

Figure 2-5. Conceptual Layout--System Option 1

Manure Digestion. Table 2-15 lists the design criteria used for sizing the digstion system and its auxiliary components. As the design parameters indicate, the digester would have enough capacity to treat all the manure produced. The manure flow scheme includes several key components: (1) a mixing tank to dilute the manure to the appropriate solids content; (2) an in-line grinder to render the sludge more homogeneous; (3) a positive displacement pump; (4) a spiral type heat exchanger to transfer heat to the raw sludge; and (5) a recirculation pump to circulate digester contents.

The digester sizing criteria assume a manure feed solids concentration of 7 percent, with a corresponding hydraulic detention time of 15 days. The digester system and associated equipment were selected to allow processing of somewhat higher solids concentrations. Higher solids concentrations could enhance gas production since the residence time in the digester will increase. The digested manure would also be less putrescible. Table 2-16 presents a mass balance on the system.

Cogeneration. Table 2-15 also outlines the cogeneration system design criteria. The engine generator set was sized for the average electrical demand of Montana Farms. The engine would consume only about 75 percent of the biogas produced under average conditions. The remaining fuel would be available for space heating of the laying houses in the winter.

Table 2-15. System Option 1 Design Criteria

Item	Value
Manure digestion system	
Rate of manure production, lbs/day	27,500
Dilution water flow, gpd	8,480
Total sludge flow, gpd	11,770
Sludge solids content, percent	7
Liquid detention time, day	15
Number of digesters	1
Digester diameter, ft	35
Digester height, ft	24
Average gas production, million Btu/hr	1.01
Heating value of gas, Btu/cu ft	600
Heat exchanger capacity, 1000 Btu/hr	256
Cogeneration system	
Rated generator output, Kw (a)	60.7
Fuel consumption, million Btu/hr	0.74
Recoverable heat, million Btu/hr (b	0.39
Engine efficiency, percent	28
Output voltage	480
Rotational speed, rpm	1,200
Manure drying	
Drying lagoons	
Number	8
Length and width, ft.	80 X 80
Depth, ft.	4
Supernatant lagoons	
Number	1
Length and width, ft.	160
Depth, ft.	4

(a) Derated for 600 Btu/scfm gas and site elevation
(b) 175 degrees F. hot water

Table 2-16. Mass Balance--System Options 1 and 3

Item	Volume, gpd	Solids content, percent	Weight of dry solids, ppd
Raw manure	3,300	25	6,875
Dilution water	8,500	--	--
Digester feed	11,800	7	6,875
Stabilized manure	11,800	4.5	4,400
Dried manure	1,800	30	4,400

The engine generator set would have the capability to burn propane as alternate fuel. This option would be particularly valuable during system startup, when initially heating the digester contents would be required.

Thermal energy would be recoverd from both the engine cooling water and the hot exhaust gases. When the heat produced by the engine exceeds the heating demand, a fan cooled radiator would waste the excess heat to the atmosphere. Under normal operating conditions, the generated heat would be distributed by hot water piping to the point of use. The engine, generator, heat recovery equipment, electrical switchgear, and control equipment would be furnished as one complete package. This approach reduces installation costs, assures equipment compatibility, and requires one vendor to be responsible for all cogeneration equipment.

The cogeneration will satisfy the efficiency requirements under the Public Utility Policy Regulatory Act (PURPA) of 1978 and can operate in parallel with the local power grid. Excess electricity would be produced that could be wheeled through the Vigilante Electrical Cooperative system for sale to Montana Power Company.

Since Montana weather is severe in the winter, a 20-foot by 20-foot insulated building would house the cogeneration equipment and all digestion equipment except the mixing and digestion tanks. This would provide protection for this equipment and ensure maximum reclamation of the radiant heat generated by the engine, heat recovery units, and interconnecting and exhaust piping. All outside piping would be buried below the frost line or heat taped and insulated to prevent freezing.

Digested manure would be conveyed by gravity to lagoons for drying. A layout of the lagoon area is presented on Figure 2-6. The supernatant lagoon area would be excavated to provide fill for the drying lagoon berms. Removable stop logs would be used to permit decanting of supernatant from the drying lagoons.

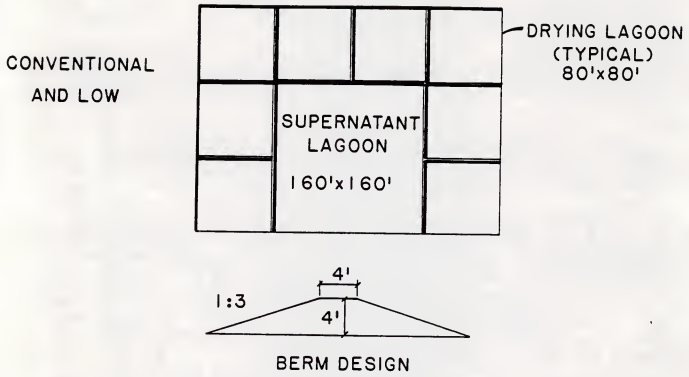

Figure 2-6. Conceptual Layout--Manure Drying Lagoons

Operation of the digestion/cogeneration systems would be relatively easy but would require some daily attention. It is anticipated that the mixing tank would be charged with manure on a daily basis and the sludge would be pumped to the digester continuously. The system would allow for the use of heated mixing water in the winter to prevent sludge freezing. The sludge heat exchanger would automatically maintain a set discharge temperature. This set point would be correlated with the digester temperature and modified on a seasonal basis to maintain a digestion temperature of 95°F. It is expected that the digester would require periodic cleaning. Normally this would be done on a 3- to 5-year cycle. Debris which has accumulated could be pumped with wash water to the drying lagoons.

The engine-generator system would operate automatically. Included in the control system are all the safety shutdown and alarm circuitry required for a safe operating system.

In addition to the normal operation of the system, routine maintenance would be required for all mechanical equipment. Lubrication of all rotating equipment would be required at intervals recommended by the specific equipment manufacturer. The engine would require the most maintenance attention. Maintenance service contracts are usually available through the equipment distributor for major overhauls but regular tune-up and maintenance are often carried out by the owner. For the system described here, the engine would require minor service every 720 hours (change oil and oil filters and air filters), a top end overhaul every 10,000 hours, and a major overhaul every 20,000 hours. Minor overhauls should take no more than 2 to 4 hours, so the digestion process would not be disrupted. The 10,000 hour overhaul can likewise be of short duration by using exchange parts. For the 20,000 hour overhaul, the engine would be off-line for several days. This shutdown would be a good opportunity for periodic digester cleaning.

System Option 2: Innovative Technology

With System Option 2, manure would be collected in solid form. Each day about 460 cubic feet of manure would be loaded into a live bottom feed bid. Twin 4-inch screw conveyors would be used to meter the manure into either a mixing tank or an agitator mixer. Use of a mixing tank would allow the system to be used in a conventional mode. For the purposes of this evaluation, the same size mixing tank would be used in all option. An 8 gpm sludge pump would be used to convey digester contents to the mixing tank where it would be mixed with 2.4 gpm of manure. The mixture would be pumped through a grinder and heat exchanger en route to the digester.

Figure 2-7 presents a schematic flow diagram and energy balance for the system. A conceptual layout is presented in Figure 2-8, and a mass balance is presented in Table 2-17.

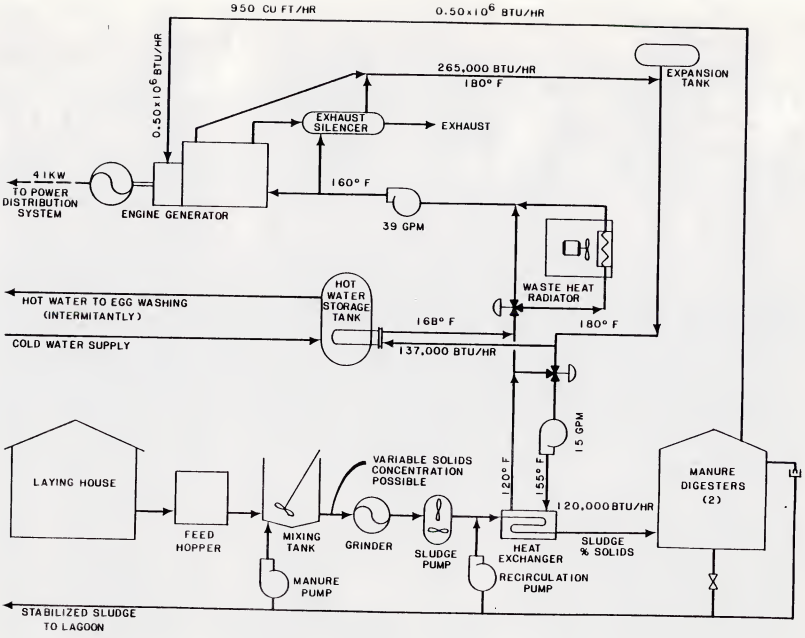

Figure 2-7. Schematic Flow Diagram and Energy Balance: System Option 2

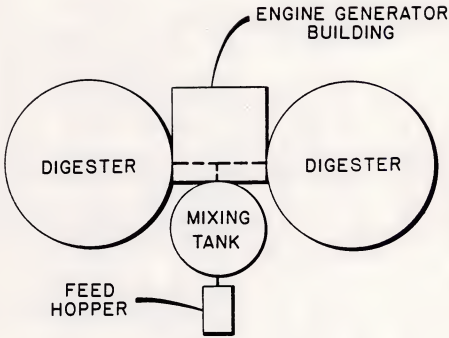

Figure 2-8. Conceptual Layout--System Option 2

Table 2-17. Mass Balance--System Option 2

Item	Volume, gpd	Solids content, percent	Weight of dry solids, ppd
Raw manure	3,300	25	6,875
Digester feed	3,300	25	6,875
Stabilized manure	3,800	11	4,400
Dried manure	1,800	30	4,400

Manure Digestion. Two anaerobic digesters of the same size as that used for System Option 1 would be used for System Option 2. System design criteria are presented in Table 2-18. Because the manure would be less dilute, a longer hydraulic detention time would be provided. A chemical feed system would be provided to allow feeding of calcium chloride to the digester for pH control.

Cogeneration. Design criteria for the cogeneration system associated with System Option 2 are also presented in Table 2-5. With this option, no biogas would be available for space heating as all of it will be used as fuel for the engine generator. As with System Option 1, excess thermal energy would be available over that required for raw manure and digester heating.

Sludge Drying and Disposal. Use of undiluted manure would allow a significant reduction in the area of both the sludge drying lagoons and the supernatant lagoon. Transport of digested manure to the drying lagoons would be more difficult due to its higher solids content. For this reason, pumping of digested manure to the lagoons (at very low velocities) is assumed.

System Option 3: Low Technology

Because a 7 percent slurry is required, manure collection mixing and feeding would be as in System Option 1. In the past, packaged low technology systems for chicken manure were marketed by Energy Cycle, Inc. Operational problems with a digester installed at a layer operation in Arkansas have caused Energy Cycle, Inc., to no longer supply their systems to egg producers. The problem involved was the formation of a "concrete" on the bottom of the digester that was apparently derived from the limestone grit fed to the chickens. A settling of grit occurred in the laboratory testing conducted during this research. We, therefore, believe that grit buildup would occur at a significant rate with this technology.

Manure Digestion. Digestion would occur in a buried concrete tank with a rubber sheeting cover. The tank would be much longer than wide or deep to assure plug flow through the tank. Heating of the digester would be accomplished by removing from the top of the digester contents at intervals along its length, pumping it through

Table 2-18. System Option 2 Design Criteria

Item	Value
Manure digestion system	
Rate of manure production, lbs/day	27,500
Dilution water flow, gpd	0
Total sludge flow, gpd	3,440
Sludge solids content, percent	25
Liquid detention time, day	100
Number of digesters	2
Digester diameter, ft	35
Digester height, ft	24
Average gas production, million Btu/hr	0.75
Heating value of gas, Btu/cu ft	500
Heat exchanger capacity, 1000 Btu/hr	512
Cogeneration system	
Rated generator output, Kw (a)	41.0
Fuel consumption, million Btu/hr	0.56
Recoverable heat, million Btu/hr (b	0.26
Engine efficiency, percent	28
Output voltage	480
Rotational speed, rpm	1,200
Manure drying	
Drying lagoons	
Number	9
Length and width, ft.	40 X 40
Depth, ft.	4
Supernatant lagoons	
Number	1
Length and width, ft.	80
Depth, ft.	4

(a) Derated for 600 Btu/scfm gas and site elevation
(b) 175 degrees F. hot water

an external heat exchanger, and returning it to the bottom of the tank at intervals along the tank's length. Design criteria are presented in Table 2-19.

Figure 2-9 presents a schematic flow diagaram and energy balance for the system. A conceptual layout is presented in Figure 2-10. For mass balance data, refer to Table 2-16.

Cogeneration. Cogeneration equipment would be the same as that used for System Option 2. Design criteria are presented in Table 2-6.

Sludge Drying and Disposal. Sludge drying and supernatant lagoon sizes would be as indicated for System Option 1. A layout of the lagoons was presented in Figure 2-6.

Table 2-19. System Option 3 Design Criteria

Item	Value
Manure digestion system	
Rate of manure production, lbs/day	27,500
Dilution water flow, gpd	8,480
Total sludge flow, gpd	11,770
Sludge solids content, percent	7
Liquid detention time, day	20
Number of digesters	1
Digester width, ft	25
Digester depth, ft	16
Digester length, ft	80
Average gas production, million Btu/hr	1.01
Heating value of gas, Btu/cu ft	600
Heat exchanger capacity, 1000 Btu/hr	299
Cogeneration system	
Rated generator output, Kw (a)	41.0
Fuel consumption, million Btu/hr	0.56
Recoverable heat, million Btu/hr (b	0.26
Engine efficiency, percent	28
Output voltage	480
Rotational speed, rpm	1,200
Manure drying	
Drying lagoons	
Number	8
Length and width, ft.	80 X 80
Depth, ft.	4
Supernatant lagoons	
Number	1
Length and width, ft.	160
Depth, ft.	4

(a) Derated for 600 Btu/scfm gas and site elevation
(b) 175 degrees F. hot water

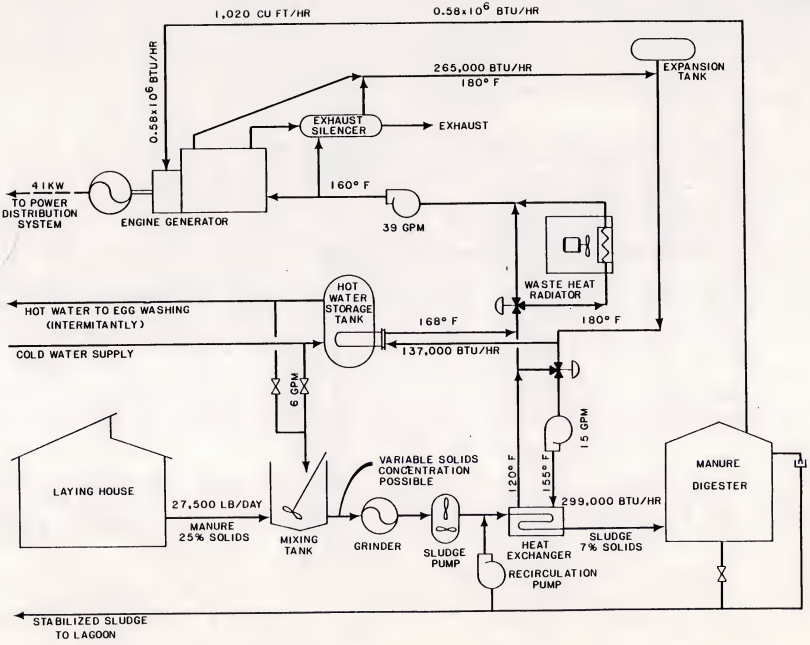

Figure 2-9. Schematic Flow Diagram and Energy Balance: System Option 3

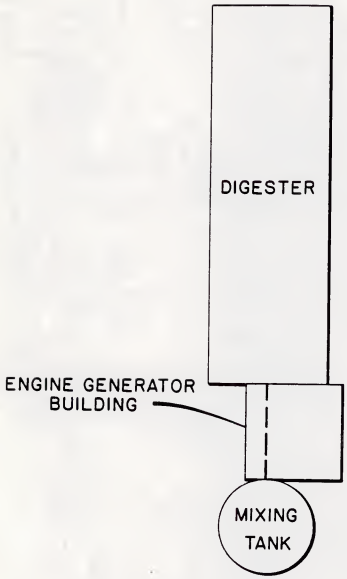

Figure 2-10. Conceptual Layout--System Option 3

SECTION 3

PROJECT ECONOMICS

This section presents an economic evaluation of the three optimized systems described in Section 2. A summary of the costs and benefits of each system is given and the economics of the three systems are compared to the "no project" alternative. An analysis of the sensitivity of the evaluation to principal cost factors is given and a recommended project is selected.

BASIS OF COST AND BENEFIT ESTIMATES

Costs and benefits for the three options were estimated using a consistent basis. The procedures used in estimating capital costs, operation and maintenance costs, cost savings and revenue, and tax savings are presented.

Option costs include all costs that would be incurred for manure collection, anaerobic digestion, cogeneration, use of generated energy, and manure drying and disposal during a 10-year planning period. The salvage value of system components at the end of the planning period is ignored.

Cost evaluations presented herein assume that all price levels will increase at an annual rate of 5 percent per year over the next 5 years. Different rates of inflation are evaluated in the sensitivity analysis portion of this section.

Capital Costs

Unless noted otherwise, capital costs stated herein are expressed at mid-1984 price levels. Construction labor costs are based on hourly rates for craftsmen in large metropolitan areas and hence may be higher than those charged in the Townsend area. Typical wage rates for this analysis, including contractor's overhead and profit, are as follows:

Category	Hourly rate
Carpenter	$27.70
Plumber	31.75
Electrician	31.65
Heavy equipment operator	29.10

Engineering fees include design services plus limited assistance during construction and startup. Cost estimates assume that Montana Farms will act as the general contractor, using local specialty contractors for mechanical, electrical, and civil work. All

equipment is assumed to be new and equipment costs are based on manufacturers' quotes. Lower costs would result from competitive bidding. Used equipment could also be substituted to reduce capital costs.

Loan repayment terms assume the use of conventional financing for a 6-month construction loan (at an interest rate of 20 percent per year) and long-term (10-year) financing using a subsidized interest rate of 10 percent per year. Such long-term financing may be available through the Montana Renewable Energy and Conservation Program.

Operation and Maintenance Costs

Annual operation and maintenance costs for the initial year of operation were estimated by multiplying the following unit labor costs by the estimated annual manhour requirement for operation and maintenance activities:

Category	Hourly rate
Operation	$15.00
Administration	20.00

Annual operation and maintenance cost for the initial year of operation of the engine generator were estimated using a unit cost of $0.0167 per kilowatt hour.

Cost Savings and Revenue

Reduction in electricity and propane purchases would result in cost savings. Electricity cost savings estimates for the initial year of operation of the systems reflect the current rates charged by the Vigilante Electric Cooperative, Inc. Current rates, under Rate Schedule GS, are as follows:

Type of charge	Amount
Base (capacity) charge	$0.90 per KVA
Energy charge	$0.0465 per kwh
Demand charge	$3.75 per kw over 50 kw

We have assumed that Montana Farms would continue to require the same transformer capacity under all options, and, therefore, no savings in base charges would be possible. We have also assumed that this base charge revenue would meet the cooperative's minimum charge requirements.

Initial year propane cost savings estimates are based on a cost of $0.585 per gallon.

Electricity sales revenue is based on wheeling power through the cooperative's system to Montana Power Company. A fully levelized energy rate for a 10-year contract of $0.0468 per kwh has been used. Revenue associated with the capacity rate is assumed to be negligible. A wheeling charge of $0.005 per kwh has been assumed. Actual charges would have to be negotiated with the cooperative.

Tax Savings

Implementation of the systems described in this report would allow Montana Farms to gain federal income tax benefits. An increase in taxable income, deductions, and tax credits would occur.

Income. Savings in the cost of energy would increase taxable income to Montana Farms. An increase in income tax would result.

A significant increase in taxable income could result if Montana Farms were to receive a grant from the State of Montana to reduce the construction cost of the project. Grant payments are taxed as regular income.

Deductions. Businesses can deduct from gross income the expenses of generating that income. In this instance, operation and maintenance expenses, interest expenses, local and state taxes, and depreciation (less system cost savings and revenue) would be allowable deductions. Under the accelerated cost recovery system, capital investment in equipment required for the systems under study could be depreciated over 5 years using the following percentages:

Year	Percentage
1	15
2	22
3-5	21

In the event capital investments were considered research and experimental expenditures, they could be depreciated over 3 years. To be conservative, a 5-year depreciation schedule is used herein.

Income tax savings due to deductions assume that the owners of Montana Farms are in the 25 percent federal income tax bracket and the 10 percent state tax bracket. That is, we have assumed that identified tax deductions would result in tax savings equal to 35 percent of the deduction amount.

Tax Credits. The investments called for herein would qualify for both the regular investment tax credit and the biomass property energy investment tax credit. The amounts of those credits are as follows:

Type	Percentage
Regular	10
Energy (biomass)	10

The basis of property used in depreciation calculations must generally be reduced by 50 percent of the total tax credits received. Tax credits (25 percent) are also available for increases in non-capital and non-grant funded research and experimentation expenditures.

SUMMARY OF PROJECT ECONOMICS

Economic costs and benefits are associated with each of the alternatives. A summary of those factors is presented below.

No-Project Alternative

The no-project alternative calls for no immediate capital investment. We have assumed that replacement of the existing front end loader and manure spreader would not be required during the next 10 years.

Operation and Maintenance Cost. The annual operation and maintenance cost of this option would be $15,000 in 1985.

Summary of Project Economics. A summary of the costs and benefits associated with this option is presented in Table 3-1. No cost savings or revenues are anticipated.

System Option 1: Conventional Technology

System Option 1, Conventional Technology, calls for a substantial initial capital investment and for substantial increases in operation and maintenance costs.

Capital Cost. The estimated capital cost of this option is presented in Table 3-2.

Operation and Maintenance Cost. The annual operation and maintenance cost of this option is presented in Table 3-3.

Summary of Project Economics. A summary of the costs and benefits of this option is presented in Table 3-4.

Table 3-1. Project Economics: No-Project Option

Item/year	Amount, thousand dollars										
	0	1	2	3	4	5	6	7	8	9	10
Capital investment	0	0	0	0	0	0	0	0	0	0	0
Loan repayment	0	0	0	0	0	0	0	0	0	0	0
Annual O&M cost	15.00	15.75	16.54	17.36	18.23	19.14	20.10	21.11	22.16	23.27	24.43
Cost savings and revenue	0	0	0	0	0	0	0	0	0	0	0
Tax benefits	5.25	5.51	5.79	6.08	6.38	6.70	7.04	7.39	7.76	8.14	8.55
Net revenue or cost(-)	-9.75	-10.24	-10.75	-11.29	-11.85	-12.44	-13.07	-13.72	-14.41	-15.13	-15.88
Cumulative net revenue or cost(-)	-9.75	-19.99	-30.74	-42.02	-53.87	-66.32	-79.38	-93.10	-107.5	-122.6	-138.5

Table 3-2. Estimated Capital Cost: System Option 1

Item	Estimated cost, thousand dollars
Mixing tank(a)	11.00
Manure grinder	8.50
Manure pump	4.20
Manure digester(a)	53.50
Engine generator(b)	100.00
Expansion tank	0.50
Waste heat radiator(c)	3.20
Recirculation pump	4.20
Manure heat exchanger(c)	10.00
Circulation pump	0.40
Hot water storage tank(d)	5.70
Metal building	12.00
Site work	15.00
Miscellaneous piping	15.00
Miscellaneous electrical	30.00
Miscellaneous structural	5.00
Sludge drying lagoons	43.00
Subtotal	321.20
Contingencies, 10 percent	32.12
Engineering	44.00
Legal and financial	10.00
Total	407.32

(a) Includes mixer and insulation
(b) Includes exhaust heat exchanger, switchgear, battery, and 26 gpm circulation pump
(c) Includes control valve
(d) Includes heat exchanger

Table 3-3. Estimated Operation and Maintenance Cost: System Option 1

Item	Estimated cost, thousand dollars per year
Manure collection	10.00
Manure digestion	9.20
Cogeneration	8.90
Manure drying	6.10
Manure disposal	5.00
Subtotal	39.20
Administration	1.00
Total	40.20

Table 3-4. Project Economics: System Option 1, Conventional

Item/year	Amount, thousand dollars 0	1	2	3	4	5	6	7	8	9	10
Capital investment	407.32	0	0	0	0	0	0	0	0	0	0
Basis	366.59	311.60	230.95	153.97	76.98	76.98	0	0	0	0	0
Loan repayment	40.73	64.62	64.62	64.62	64.62	64.62	64.62	64.62	64.62	64.62	64.62
Annual O&M cost	15.00	40.20	42.21	44.32	46.54	48.86	51.31	53.87	56.57	59.39	62.36
Cost savings and revenue											
Electricity savings	0.00	19.00	19.95	20.95	21.99	23.09	24.25	25.46	26.73	28.07	29.48
Propane savings	0.00	7.00	7.35	7.72	8.10	8.51	8.93	9.38	9.85	10.34	10.86
Electricity sale	0.00	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70
Subtotal	0.00	29.70	31.00	32.37	33.80	35.30	36.88	38.54	40.28	42.11	44.03
Tax benefits											
Due to deduct	19.51	45.76	54.68	53.23	52.98	52.64	25.40	24.89	24.29	23.74	22.85
Due to income	0.00	-10.40	-10.85	-11.33	-11.83	-12.36	-12.91	-13.49	-14.10	-14.74	-15.41
Credits	0.00	73.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal	19.51	108.68	43.83	41.91	41.15	40.29	12.49	11.40	10.19	9.00	7.44
Net revenue or cost(-)	-36.23	33.57	-32.00	-34.67	-36.20	-37.89	-66.55	-68.55	-70.71	-72.90	-75.50
Cumulative net revenue or cost(-)	36.23	-2.66	-34.66	-69.33	-105.53	-143.42	-209.97	-278.52	-349.23	-422.13	-497.63

System Option 2: Innovative Technology

Costs associated with System Option 2, Innovative Technology, are presented below.

Capital Cost. The estimated capital cost of this option is presented in Table 3-5.

Operation and Maintenance Cost. The annual operation and maintenance cost of this option is presented in Table 3-6.

Summary of Project Economics. A summary of the costs and benefits of this option is presented in Table 3-7.

Table 3-5. Estimated Capital Cost: System Option 2

Item	Estimated cost, thousand dollars
Feed hopper	8.00
Twin screw feeder	8.00
Mixing tank(a)	11.00
Manure grinder	8.50
Manure pumps(two)	8.40
Manure digesters(two)(a)	107.00
Engine generator(b)	80.00
Expansion tank	0.50
Waste heat radiator(c)	2.50
Recirculation pump	4.20
Manure heat exchanger(c)	10.00
Circulation pump	0.40
Hot water storage tank(d)	5.70
Metal building	12.00
Site work	15.00
Miscellaneous piping	23.00
Miscellaneous electrical	30.00
Miscellaneous structural	5.00
Sludge drying lagoons	33.80
Subtotal	373.00
Contingencies, 10 percent	37.30
Engineering	44.00
Legal and financial	10.00
Total	464.30

(a) Includes mixer and insulation
(b) Includes exhaust heat exchanger, switchgear, battery, and 26 gpm circulation pump
(c) Includes control valve
(d) Includes heat exchanger

Table 3-7. Project Economics: System Option 2

Amount, thousand dollars

Item/year	0	1	2	3	4	5	6	7	8	9	10
Capital investment	464.3	0	0	0	0	0	0	0	0	0	0
Basis	417.87	355.19	263.26	175.51	87.75	87.75	0	0	0	0	0
Loan repayment	46.43	73.66	73.66	73.66	73.66	73.66	73.66	73.66	73.66	73.66	73.66
Annual O&M cost	15.00	38.20	40.11	42.12	44.22	46.43	48.75	51.19	53.75	56.44	59.26
Cost savings and revenue											
Electricity savings	0.00	18.40	19.32	20.29	21.30	22.37	23.48	24.66	25.89	27.19	28.54
Propane savings	0.00	7.00	7.35	7.72	8.10	8.51	8.93	9.38	9.85	10.34	10.86
Electricity sale	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal	0.00	25.40	26.67	28.00	29.40	30.87	32.42	34.04	35.74	37.53	39.40
Tax benefits											
Due to deduct	16.25	49.49	59.52	57.74	57.31	56.76	25.55	24.79	23.93	23.12	21.91
Due to income	0.00	-8.89	-9.33	-9.80	-10.29	-10.81	-11.35	-11.91	-12.51	-13.13	-13.79
Credits	0.00	83.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal	16.25	124.18	50.19	47.94	47.01	45.96	14.20	12.88	11.42	9.98	8.12
Net revenue or cost(-)	-45.18	37.72	-36.91	-39.83	-41.46	-43.26	-75.79	-77.93	-80.24	-82.59	-85.39
Cumulative net revenue or cost(-)	-45.18	-7.46	-44.36	-84.20	-125.65	-168.91	-244.70	-322.64	-402.88	-485.47	-570.86

Table 3-6. Estimated Operation and Maintenance Cost: System Option 2

Item	Estimated cost, thousand dollars per year
Manure collection	10.00
Manure digestion	10.10
Cogeneration	6.00
Manure drying	6.10
Manure disposal	5.00
Subtotal	37.20
Administration	1.00
Total	38.20

System Option 3: Low Technology

The costs of the Low Technology option, Syetem Option 3, are presented below.

Capital Cost. The estimated capital cost of this option is presented in Table 3-8.

Operation and Maintenance Cost. The annual operation and maintenance cost of this option is presented in Table 3-9.

Summary of Project Economics. A summary of the costs and benefits of this option is presented in Table 3-10.

Table 3-8. Estimated Capital Cost: System Option 3

Item	Estimated cost, thousand dollars
Mixing tank(a)	11.00
Manure grinder	8.50
Manure pump	4.20
Manure digester(a)	36.20
Engine generator(b)	80.00
Expansion tank	0.50
Waste heat radiator(c)	2.50
Recirculation pump	4.20
Manure heat exchanger(c)	10.80
Circulation pump	0.40
Hot water storage tank(d)	5.70
Metal building	12.00
Site work	15.00
Miscellaneous piping	15.00
Miscellaneous electrical	30.00
Miscellaneous structural	5.00
Sludge drying lagoons	43.00
Subtotal	284.00
Contingencies, 10 percent	28.40
Engineering	44.00
Legal and financial	10.00
Total	366.40

(a) Includes mixer and insulation
(b) Includes exhaust heat exchanger, switchgear, battery, and 26 gpm circulation pump
(c) Includes control valve
(d) Includes heat exchanger

Table 3-9. Estimated Operation and Maintenance Cost: System Option 3

Item	Estimated cost, thousand dollars per year
Manure collection	10.00
Manure digestion	10.60
Cogeneration	6.00
Manure drying	6.10
Manure disposal	5.00
Subtotal	37.70
Administration	1.00
Total	38.70

Table 3-10. Project Economics: System Option 3

Item/year	0	1	2	3	4	5	6	7	8	9	10
	Amount, thousand dollars										
Capital investment	366.4	0	0	0	0	0	0	0	0	0	0
Basis	329.76	280.30	207.75	138.50	69.25	69.25	0	0	0	0	0
Loan repayment	36.64	58.13	58.13	58.13	58.13	58.13	58.13	58.13	58.13	58.13	58.13
Annual O&M cost	15.00	38.70	40.64	42.67	44.80	47.04	49.39	51.86	54.45	57.18	60.04
Cost savings and revenue											
Electricity savings	0.00	15.40	16.17	16.98	17.83	18.72	19.65	20.64	21.67	22.75	23.89
Propane savings	0.00	6.40	6.72	7.06	7.41	7.78	8.17	8.58	9.01	9.46	9.93
Electricity sale	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal	0.00	21.80	22.89	24.03	25.24	26.50	27.82	29.21	30.67	32.21	33.82
Tax benefits											
Due to deduct	18.07	42.05	50.12	48.87	48.69	48.43	23.98	23.58	23.10	22.67	21.94
Due to income	0.00	-7.63	-8.01	-8.41	-8.83	-9.27	-9.74	-10.22	-10.74	-11.27	-11.84
Credits	0.00	65.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal	18.07	100.37	42.11	40.45	39.86	39.16	14.24	13.35	12.36	11.39	10.10
Net revenue or cost(-)	-33.57	25.35	-33.77	-36.30	-37.83	-39.51	-65.45	-67.42	-69.54	-71.70	-74.24
Cumulative net revenue or cost(-)	-33.57	-8.22	-41.98	-78.29	-116.12	-155.63	-221.08	-288.50	-358.04	-429.75	-503.99

COMPARISON OF SYSTEM OPTIONS

An economic comparison of system options is presented in Table 3-11. Review of the information presented in Table 3-11 indicates that the least expensive option for Montana Farms would be to take no action. Apparently, current energy costs in Montana are not high enough to justify the significant capital investment required for biogas production and cogeneration.

System Option 1, Conventional Technology, is the apparent best action alternative. Its capital cost is higher than that of System Option 3, and lower than that of System Option 2. It has the highest operation and maintenance cost, and would produce the highest cost savings and revenue.

Table 3-11. Economic Comparison of System Options

Item	Amount, thousand dollars: No project	System Option 1	System Option 2	System Option 3
Capital cost	0	407.32	464.3	366.40
Initial year				
Loan repayment	0	64.62	73.66	58.13
O&M cost	-15.75	40.20	38.20	38.70
Cost savings and revenue	0	29.70	25.40	21.80
Tax benefits	5.25	108.68	124.18	100.37
Net revenue or cost(-)	-9.75	33.57	37.72	25.35
Ten-year cumulative net revenue or cost(-)	-138.50	-497.63	-570.86	-503.99

SENSITIVITY ANALYSIS

It is appropriate to analyze the sensitivity of the apparent best action alternative to principal cost factors. Principal cost factors evaluated below include the following:

Grant funding to reduce investment cost.
Rate of increase of energy cost.

Grant Funding

Grant funding could be sought from the Montana Renewable Energy and Conservation Program for Fiscal Conservation. For fiscal year 1985, the maximum grant available from that program is $333,600. Table 3-12 presents the project economics for System Option 1 with the capital investment reduced by the maximum grant amount to $73,720.

Rate of Energy Cost Increase

Table 3-13 presents the project economics of System Option 1 with a 10 percent per year increase in energy costs (savings) rather than the 5 percent per year assumed in the original analysis.

Table 3-13. Project Economics: With 10 Percent Per Year Increase in Energy Costs

Amount, thousand dollars

Item/year	0	1	2	3	4	5	6	7	8	9	10
Capital investment	73.72	0	0	0	0	0	0	0	0	0	0
Basis	366.59	311.60	230.95	153.97	76.98	76.98	0	0	0	0	0
Loan repayment	7.37	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.69
Annual O&M cost	15.00	40.20	42.21	44.32	46.54	48.86	51.31	53.87	56.57	59.39	62.36
Cost savings and revenue											
Electricity savings	0.00	19.00	20.90	22.99	25.29	27.82	30.60	33.66	37.03	40.73	44.80
Propane savings	0.00	7.00	7.70	8.47	9.32	10.25	11.27	12.40	13.64	15.01	16.51
Electricity sale	0.00	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70
Subtotal	0.00	29.70	32.30	35.16	38.31	41.77	45.57	49.76	54.37	59.43	65.01
Tax benefits											
Due to deduct	7.83	35.82	45.35	44.62	45.19	45.78	19.45	20.07	20.70	21.38	22.03
Due to income	-166.80	-10.40	-11.31	-12.31	-13.41	-14.62	-15.95	-17.42	-19.03	-20.80	-22.75
Credits	0.00	81.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal	-158.97	106.89	34.04	32.32	31.79	31.16	3.50	2.65	1.67	0.58	-0.72
Net revenue or cost(-)	-181.34	84.69	12.44	11.46	11.86	12.37	-13.93	-13.15	-12.22	-11.08	-9.77
Cumulative net revenue or cost(-)	-181.34	-96.65	-84.21	-72.75	-60.89	-48.52	-62.45	-75.60	-87.82	-98.90	-108.67

(a) Grant income is taxed at 50 percent

Table 3-12. Project Economics: With Grant Funding

Amount, thousand dollars

Item/year	0	1	2	3	4	5	6	7	8	9	10
Capital investment	73.72	0	0	0	0	0	0	0	0	0	0
Basis	366.59	311.60	230.95	153.97	76.98	76.98	0	0	0	0	0
Loan repayment	7.37	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.69
Annual O&M cost	15.00	40.20	42.21	44.32	46.54	48.86	51.31	53.87	56.57	59.39	62.36
Cost savings and revenue											
Electricity savings	0.00	19.00	19.95	20.95	21.99	23.09	24.25	25.46	26.73	28.07	29.48
Propane savings	0.00	7.00	7.35	7.72	8.10	8.51	8.93	9.38	9.85	10.34	10.86
Electricity sale	0.00	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70
Subtotal	0.00	29.70	31.00	32.37	33.80	35.30	36.88	38.54	40.28	42.11	44.03
Tax benefits											
Due to deduct	7.83	35.82	45.35	44.62	45.19	45.78	19.45	20.07	20.70	21.38	22.03
Due to income	-166.80	-10.40	-10.85	-11.33	-11.83	-12.36	-12.91	-13.49	-14.10	-14.74	-15.41
Credits	0.00	81.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal	-158.97	106.89	34.50	33.30	33.36	33.42	6.54	6.58	6.60	6.64	6.62
Net revenue or cost(-)	-181.34	84.69	11.59	9.65	8.93	8.16	-19.57	-20.45	-21.37	-22.33	-23.40
Cumulative net revenue or cost(-)	-181.34	-96.65	-85.06	-75.41	-66.48	-58.32	-77.89	-98.34	-119.71	-142.04	-165.45

(a) Grant income is taxed at 50 percent

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

Major Findings and Recommendations

The major findings and recommendations of this report are as follows:

1. Production of biogas from layer manure is technically feasible.

2. Close temperature control, adequate mixing, and control of digester pH are necessary. Digester pH control can be achieved by adding dilution water or a buffering chemical to the manure.

3. Costs associated with biogas production and cogeneration cannot now be recovered through energy savings and sale because of the relatively low cost of energy currently available to Montana Farms.

4. We recommend that Montana Farms seek grant funding from the Montana Renewable Energy and Conservation Program for preparation of a detailed design of System Option 1 and negotiation of wheeling and power sale contracts. Final design drawings and specifications could be used to obtain bids from local vendors for the construction of the project. Detailed cost and income information would then be available to Montana Farms management.

Permits and Approvals

Permits and approvals required to implement any of the action alternatives would be as follows:

1. Building permits are not required in Broadwater County outside of the City of Townsend.

2. A waste discharge permit from the Montana Department of Health and Environmental Sciences, Water Quality Bureau, could be required. Permits have not been required to date, but, according to Bureau staff, could be required in the future.

3. A long-term power purchase agreement would have to be negotiated with Montana Power Company.

4. A wheeling agreement would have to be negotiated with Vigilante Electric Cooperative, Inc.

Implementation Plan

Should Montana Farms decide to implement one of the action alternatives, the following implementation schedule should be followed:

Item	Time
Prepare grant and loan application	Due November 1 and October 1, respectively.
Obtain grant	May 1985
Negotiate agreements	June 1985
Design system	June and July, 1985
Construct system	July, August, and September 1985
Start up system	November and December, 1985
Begin power production	January 1986

Additional Work

Montana Farms may wish to conduct the following additional work which may result in additional income from the project:

1. Conduct a composting feasibility study to include a market assessment, pilot test of the process, and identification of a source of bulking material.

2. Increase the total solids concentration of manure fed to the digester to about 10 percent to assess the impact on biogas quantity and quality.

3. Approach the Bonneville Power Administration for grant support and/or power purchase.

APPENDIX A

REFERENCES

APPENDIX A
REFERENCES

Section 2

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APPENDIX B

LITERATURE SURVEY

INTRODUCTION

Anaerobic digestion of poultry manure could reduce the energy demands of egg production in Montana. This introduction discusses past developments that are the basis of this proposal and presents a review of the state-of-the-art of anaerobic digestion of poultry manure and use of biogas for electricity generation. The information presented in this section is organized by the three technologies that we propose to study. In general, the research will focus on the following technologies:

Conventional technology
Innovative technology
Low technology

Under each, we have reviewed the literature with respect to the following questions:

1. Can poultry manure be successfully anaerobicly digested using the technology?

2. What, if any, operating problems can be expected?

3. Will a surplus of energy remain after digestion energy requirements are met?

4. What are reasonable design criteria for the concept?

Prior to presentation of information on the alternative technologies, we present information on poultry manure characteristics. After the information on the alternative technologies, we present information on cogeneration using biogas as fuel. A list of references is presented at the end of this section.

Poultry Manure Characteristics

Sizing of any anaerobic digestion system must be based on the quantity and quality of subtrate fed to it. Bell (1) has indicated that the daily manure production of one layer is 0.25 pounds (at 25 percent solids). This value is confirmed by data from the Cooperative Extension of the University of California (2). Other methods for estimating manure production rates are given in the December 1974 issue of Fowl Tips (3).

Morris et al (4) provide data on estimated manure quantities by 1,000 pounds live weight for various animals. Assuming 4.5 pounds per bird, the daily manure production rate given for poultry is 0.27 pounds per day. Other information on poultry waste characteristics, such as percent solids and percent volatile

solids, is also given. Hassan et al (5) also gives information on fresh poultry manure moisture content.

Based on our review of these documents, we believe that sufficient data exist on general poultry manure characteristics to limit waste characterization activities during this research to quantification of relatively few parameters. Only those parameters that impact system loadings and maintenance of proper environmental conditons in the reactor will be checked.

Conventional Technology

A number of investigators have studied anaerobic digestion of poultry manure using the same technology that has been used for decades for municipal wastewater sludge processing. With this technology, fresh manure is diluted with water to form a slurry. The slurry is fermented in a mixed reactor that is heated to provide an optimum environment for mesophilic methanogenic bacteria (about 95 degrees Fahrenheit).

In 1966, Cassell and Anthonisen (6) reported that when poultry manure digesters were loaded at a rate of 0.088 pounds of volatile solids per cubic foot-day, the ammonia nitrogen concentration in the digesters reached toxic levels. Loehr (7) pointed out that ammonia toxicity could be significant problem in high rate digestion of concentrated solids with a high nitrogen content, such as poultry wastes.

Holdom and Winstrom-Olsen (8) pointed out that a 60,000 bird poultry farm could provide its own power needs plus a small surplus with anaerobic digestion of its wastes.

A field test of anaerobic digestion of poultry manure was conducted by Savery and Cruzan (9) in 1972. Two batch experiments and three continuous-flow experiments were conducted using a 35-liter cylindrical reactor. Both thermophilic (51 degree Centigrade) and mesophilic (29 degree Centigrade) conditions were studied. Batch reactor operation in the thermophilic range produced 130 liters of gas (69 percent methane) per Kg of wet manure reacted. The batch test of mesophilic digester was terminated after only 8 days. Attempts to operate the anaerobic digester at 51 degrees Centigrade in a continuous-flow, well-stirred mode with hydraulic retention times of 4. 5 and 6.7 days resulted in retarded digester operation.

Hassan et al (5) investigated the optimum conditions for methane production at a temperature of 25 degrees Centigrade plus or minus 3 degrees Centigrade which is the average temperature of broiler houses. Fresh manure (25 to 35 percent total solids) from caged layers from the University of Maine farm was used. Sawdust was added to simulate broiler manure.

Fresh manure was mixed with water to form slurries of various total solids concentrations and the slurries were incubated in one-liter flasks in batch tests. The flasks were shaken once per day. Initial total solids on the digesters varied from 1.9 to 19.7 percent. Maximum 70 day methane production volumes occurred in the 4 to 7 percent total solids range.

Hassan et al (5) also established the total solids feed concentration that would minimize the recharging interval for a batch-fed digester. The recharging interval was defined as that period after which the rate of methane production begins to decline. which was found to coincide with the time elapsed for 70 to 80 percent of total methane production. He found that the optimum total solids feed concentration was 7 percent. Thus. the time it took to achieve 70 to 80 percent of the methane potential of poultry manure was a minimum at a total solids concentration of about 7 percent.

A paper presented by Smith et al (10) in 1979 reviewed available information on anaerobic digestion of animal manures using conventional municipal sludge processing technology. The following design criteria were proposed for laying hen manure digestion:

Item	Value
Loading rate.	
g VS/liter-day	1.5
(lb VS/cu ft-day)	0.09
Detention time.	
days	40-50
Volatile solids	
reduction. percent	55

The proposed detention time for digesting poultry manure was derived from Converse et al (11).

An analysis of the energy required to heat slurry obtained from a cold animal confinement area indicated that some form of effluent-to-influent heat exchanger was advisable. About 75 to 150 millimeters of insulation was recommended to reduce heat losses from above-ground digesters to negligible levels.

Mixing requirements were discussed at some length. A mixing intensity of 50 W/cu m was recommended for poultry manures. Intermittent mixing using an impellar with a 30 minute every 300 minute duty cycle was recommended.

Congeneration of electrical and thermal energy in modified diesel engine-generators was proposed. Waste heat from the engine cooling system would be used to heat the digester. Smith et al (10) estimated that about 20 percent of the energy in the biogas could be recovered as electrical energy and about 55 percent as heat.

In another investigation. Hassan et al (12) conducted laboratory and field-scale tests of methane production from poultry manure. Manure was collected from a pit under caged Black Cross laying hens at the University of Maine Farm. The total solids concentration of the fresh manure ranged from 25 to 28 percent during the Spring. Fall and Winter months. and from 35 to 40 percent during the Summer months.

The laboratory tests were used to assess the effect of initial solids concentration. carbon: nitrogen ratio. inoculum. and temperature on methane production. The batches of manure tested were maintained at 35 degrees Centigrade and mixed once daily by manual shaking. The initial solids tests were run for 110 days on substrates that varied from 1.9 to 19.7 percent total solids. The results suggested that operating poultry manure anaerobic digesters at total solids concentrations of 7 to 7.5 percent would maximize methane production. The authors postulated either high substrate inhibition or toxic compound inhibition (eg. ammonia) as the reason for lower methane production rates at high total solids concentrates.

The investigators also found that methane production could be increased by adding a biodegradable carbon source to the manure (eg. potatoe waste or sawdust). of inoculum and by maintaining the digesters as near 35 degrees centigrade as possible. The results of the field test indicated that methane production of 130 to 160 liters per kilogram (2 to 2.5 cubic feet per pound) of dry manure were possible. The methane content of the biogas was 59 to 60 percent. The biogas also contained 4 to 7 parts per minute of hydrogen sulfide and water vapor. a potentially extremely corrosive combination. Feathers in the manure. especially with a flock of molting hens. caused pump clogging problems.

In 1977. Converse et al (11) reported the results of full-scale testing of anaerobic digestion of layer manure in Ripon. Wisconsin. A 96.65 cubic meter digester with a design similar to that used to process municipal wastewater treatment sludge was operated over an eleven-month period. The digester was constructed of monolithic concrete and had a floating cover and a cone-shaped bottom. It was insulated and partially earth sheltered. The digester was mixed using a propeller in a draft tube and was headed to 35 degrees Centigrade with a biogas-fueled boiler with iron pipe heat exchangers. The manure was pushed into a rectangular tank located beneath the cages and diluted with

water daily prior to being fed to the digester. Digested sludge was conveyed by gravity to an earthen storage basin.

Operating data for the four test periods is summarized below:

Item	Value 1	2	3	4
Length of test, days	66	64	91	121
Loading rate, kg VS/cu m-day	1.60	1.98	2.02	1.42
(lb VS/cu ft-day)	0.10	0.12	0.13	0.09
Detention time, days	44	31	42	53
Influent total solids conc., percent	10.9	8.8	12.8	11.1
Contents ammonia-nitrogen conc., mg/l as N	7.055	6,219	8.062	8.005
Biogas production rate, cu m/ kg VS added	0.36	0.37	0.38	0.47
Methane content percent	62	56	59	63

These investigators found that with sufficient digestion insulation, net energy output was 50 to 75 percent of the gross energy output of this system.

In 1978, Rockey et al (13) reported the results of a very large scale (1,900 cubic meter) test of anaerobic digestion of layer manure in West Union, Iowa. The system was used to digest the manure from 160,000 birds. Two-stage digestion occurred in a two compartment, reinforced concrete tank, octagonal in cross section. The tank was buried but the roof was exposed.

Manure was conveyed to a mixing tank where supernatent from the secondary digester was used for dilution. Gas mixing of the digesters was accomplished by blowing biogas up through heat

exchanger/draft tubes. The digester was heated by pumping heated water through the heat exchanger draft tubes.

Daily scraping of manure was found to reduce wear on the manure collection scrapers and the amount of labor required. Manure was passed through a bar screen prior to dilution to remove dead birds. Because the ration fed the birds contained grit, the dilution and mixing basin was also used for grit removal. Problems with slurry pumping, digester mixing, and maintaining the digester at 35 degrees Centigrade during the Winter were reported.

Although operational problems prevented steady-state operation, the following approximate operating parameters were reported:

Item	Value
Loading rate, kg VS/cu m-day (lb VS/cu ft-day)	1-2 (0.06-0.13)
Hydraulic retention time, days	57
Volatile solids destruction, percent	44
Contents ammonia nitrogen concentration, mg/l as N	8.700-10.500
Biogas production rate, cu m/kg VS added	0.27
Biogas methane content, percent	40

Innovative Technology

A significant impediment to the widespread use of the anaerobic digestion process on animal manures is the practice of adding water to semi-solid manure to form a slurry to facilitate fermentation. The disadvantages of this practice include: (1) increasing the volume of the waste stream, (2) increasing the amount of energy required to heat the waste input to the process, and often, (3) increasing the size of the digester.

The proposed research will also assess the feasibility of effectively anaerobicly fermenting animal waste in a semi-solid state. The effectiveness of the process will be increased by: (1) conducting the process under optimum environmental conditions and (2) mixing the contents of the fermentor. Other researchers have shown that anaerobic fermentation can take place at high total solids concentrations, but at reduced effectiveness. These researchers have not, however, operated the process under the conditions proposed to be used by the research.

In 1947, Keefer (14) conducted batch anaerobic fermentation experiments on mixtures of raw primary sludge and digested sludge, coagulated with ferric chloride, and dewatered on a Buchner funnel. This process produced sludges that range in total solids concentrations from about 15 to 32 percent. Two controls, one with and one without ferric chloride addition, were used. Lime was added to each mixture to raise the pH to 6.7 and each was incubated at 37 degrees Centigrade.

After 20 days of fermentation, the total gas produced by the high solids units was less than 20 percent of that produced by the untreated control. Gas production was also less from units to which ferric chloride was added.

In 1958, Schulze (15) conducted batch fermentation experiments at increased solids concentrations. The substrate was was centrifuged, air-dried and ground primary sludge and air-dried, ground, digested primary sludge. The material in the fermentation units was maintained at a temperature of 32 degrees plus 1 degree Centigrade and continuously stirred at a speed of 4 revolutions per minute (rpm). In an initial set of experiments, seeding material and varying amounts of distilled water were added to the substrate to produce 10, 20, 30, 40, 50 and 60 percent dry solids. A control unit contained the seed material at 2.7 percent dry solids. Schulze found that the gas production rate decreased rapidly with increasing solids concentrations. In all experiments with solids concentrations in excess of 10 percent, the gas production rate decreased to zero after six days.

In a second set of experiments, an attempt was made to increase the solids concentrations gradually by adding dry digested solids in increments of 100 g. He found that it was possible to obtain normal methane fermentation at solids concentrations up to 37 percent.

In 1975, Wong-Chong (16) conducted batch-type experiments of anaerobic fermentation of fresh dairy manure and aged (partially composed) dairy manure and poultry manure. In his first experiment, the initial solids concentration of the substrate was about 21 percent. The temperature fluctuated from 70 degrees to 82 degrees F over the 140 day test period. No control was used.

The second experiment showed that fresh manure produced more gas than aged manure. The attempt to digest poultry manure failed, reportedly due to high ammonium concentrations.

A batch fed test was also run. In this experiment, fresh dairy manure was added to a reactor at irregular intervals. A significant increase in gas production was produced by mixing the reactor by hand stirring during two of the batch feedings.

In 1980, Wujcik and Jewell (17) conducted a series of experiments to study "dry" manure anaerobic digestion. Their first experiment was a feasibility study to determine whether anaerobic fermentation occurred at solids concentrations greater than 20 percent. Bench-scale reactors with dairy manure and wheat straw as substrate were operated at solids retention times (SRTs) of 10 and 20 days. Feed total solids concentrations were 2.5 and 5.0 percent for the control units and 25 percent for the semi-solid units. At an SRT of 20 days, gas production from the unmixed semi-solid reactor was 75 percent of the average gas production from the control units. During the feasibility study, the organic loading rate on the semi-solid reactor was 7 to 14 times higher than the organic loading rate on the control units. Thus, in these experiments, the loading rate was an uncontrolled variable.

In a second set of experiments, termed a moisture-content study, a series of batch tests, with solids concentration ranging from 10 percent to 70 percent were run. The substances were mixtures of fresh dairy manure, dried dairy manure, and tap water. All of the mixtures contained the same amount of substrate, bio-degradable volatile solids. Unfortunately, other variables known to affect gas production rates (e.g., substrate sodium and ammonia concentrations, and pH) were not controlled. Furthermore, because both ammonia and pH concentration were not controlled, the free ammonia concentration (its most toxic form) were not contolled. In 1979, Kroeker et al (24) showed that anaerobic digestion process inhibition by ammonia appeared to be the result of excessive concentrations of free ammonia rather than ammonium ion.

The objective of a third set of experiments was to determine the inhibiting effect of ammonia and chloride (constitutents normally associated with increased solids concentrations) on the effectiveness of the anaerobic fermentation process. Inhibition of as production by high ammonia concentrations was noted. Unfortunately, the tests were run over only a 30 to 40 day period. Kotze et al (25) monitored the enzymatic activity of anaerobic digesters receiving different substrates and concluded that adaptation to a substrate takes more than five weeks. Thus, the methanogenic bacteria had not been acclimated to the higher ammonia concentrations. In fact, then, the true degree of inhibition of higher ammonia concentrations under typical operating conditions was not determined.

The chloride inhibition experiments were poorly structured. The experiments varied the concentration of the anion, chloride, when it was shown in the 1961 by McCarty and McKinney (18) that the toxic action of salts is predominantly determined by the cation. Thus, it is the cation, sodium, that is the toxic constitutent of sodium chloride. Sodium concentrations in the substrate were uncontrolled, or at least unmeasured.

The fourth experiment was a pilot-scale study of batch anaerobic digestion of a mixture of dairy manure and straw at 25 percent total solids. When signs of failure appeared about 20 days into the experiment, water and 25.4 kilograms of sodium bicarbonate was added to the reactor. This amount of sodium bicarbonate would have increased the sodium concentration in the reactor by over 1,500 mg/l. In 1961, McCarty and McKinney (18) showed that the addition of 1,500 mg/l of sodium chloride as sodium to a reactor in which sodium acetate was being anaerobically fermented "caused a significant decrease in activity compared to the control." Therefore, the results of these experiments shed little light on the true feasibility of anaerobic fermentation of animal wastes of high solids concentrations.

One of the most difficult problems associated with high solids anaerobic digestion is the problem of assuring adequate mixing. It is apparent that adequate mixing would be necessary to maximize the efficiency of methane production under the less than optimal conditions of high solids anaerobic digestion.

A promising means of accomplishing the required degree of mixing is to use technology that has been applied to handling of shredded, light-fraction municipal refuse in refuse derived full (RDF) applications. Koppers (19) has proposed the use of Sprout-Waldron live-center, screw conveyor mixed bins for RDF applications. A schematic diagram of this concept is presented in Figure 1. Practical field experience with bins containing finely ground leather, floc, cut filament, rubber, plastic film and wood waste suggests that the technology could be used for handling semi-solid poultry manure.

Low Technology

It is often true that use of "low" technology, i.e., technology that minimizes mechanical equipment and operator interactions, can minimize capital and operation and maintenance costs. Low technology can also mean trouble-free and reliable operation, albeit of lower efficiency.

Some investigators have concluded that the advantages of using low technology for on-farm anaerobic digestion far outweigh

its disadvantages. In 1979. Jewell et al.. (20) examined the effect of farm size on the technical and economic feasibility of small farm methane generation using a simplified plug flow anaerobic fermentor. Hayes et al.. (21) described the development and specific economics of the same system in depth.

The plug flow reactor design from these studies has been tested on dairy cow manure at bench (20 liter). pilot (5.0 cubic meters) and full-scale (38.0 cubic meters) and has produced methane at rates up to 1.4 cubic meters of methane per cubic meter reactor-day at hydraulic retention times of 10 to 30 days: up to 40 percent destruction of solids on dairy cow manure feeds of 10 to 20 percent total solids has been achieved. This plug flow reactor was constructed from low-cost earthern and flexible materials and employed no mixing. It consistently exhibited higher conversion rates of dairy manure to biogas than were observed from a full scale conventional municipal-type digester of the same volume. operated under identical temperature and feeding conditions.

If 90 percent of the biogas could be utilized. it was concluded that methane generation costs would be competitive with then current oil and propane gas costs for farms as small as 25 to 50 total dairy cows; if 20 to 40 percent of the biogas produced must be wasted. farms of from 50 to 500 cows would find costs attractive. The system could be implemented on a 100-cow dairy farm for about $20.000. It is interesting to note that a 25.000-bird poultry farm would produce about the same amount of manure on a volatile solids basis. Anaerobic digestion of this amount of poultry manure. however. would generate almost twice as much biogas.

In 1981. Brown and Caldwell (22) proposed a low technology solution to the manure and straw disposal problem of the Del Mar Fairgrounds and Race Track in Del Mar. California. The study. developed a conceptual design for a high-solids batch digester system for the facility. Operation of the system was compatible with processing of intermittently generated large volumes of manure and straw. The reactor consisted of individual cells that were filled and sealed consecutively and then emptied in the same order after anaerobic digestion had occurred. Combustion of the biogas in an engine/generator set will produce over 3 million kilowatt-hours of electricity each year. The simple payback period of the high-solids batch digester system is estimated to be 2.3 years.

Energy Cycle of Lincoln Nebraska (23) recently installed a 90.000-gallon plug-flow digester at a 50.000 bird poultry farm near Melbourne. Arkansas. Biogas from the unit is used to fuel a

65-kilowatt engine generator. This low technology uses a lined-pit with a 30-mil loose Hypalon cover as a digester.

Biogas Cogeneration

Brown and Caldwell (26) recently completed a review of biogas utilization technologies for the U. S. Environmental Protection Agency. Biogas can be used to fuel reciprocating engines and gas turbines. Prime movers convert part of the fuel's energy to work, rejecting the remainder as waste heat. Thermal efficiency can be dramatically improved if portions of the rejected heat can be recovered and used for process or building heating (cogeneration). Waste heat recovery is more efficient if prime movers are run hot, since heat rejected at higher temperatures can be put to a greater variety of uses than heat rejected at low temperature. Also, exhaust systems last longer because corrosion is reduced.

Engines may be cooled using either a forced circulation system in which water is pumped through the engine, or a natural draft system. The equipment configuration for engine natural circulation cooling is similar to that used for boiler natural circulation systems except the engine replaces the boiler in the flow diagram. Cooling system pressures are limited to about 10 psig; if operated at higher pressures, cooling water could leak past the cylinder liner seals and into the cylinder. The maximum cooling water temperature is thus about 240 degrees F (116 degrees C), corresponding to the temperature of saturated steam at 10 psig. Engines using natural circulation cooling are relatively small, typically developing less than 1,500 horsepower (1,120 kW). Flow rates developed by natural circulation cooling may be insufficient to cool larger engines. Flow rates may be increased by installing a booster pump in the circulating loop near the entrance to the engine jacket. There are reciprocating engines on the market designed to operate at temperatures in the 160 degrees to 180 degrees F (71 degrees to 82 degrees C) range. However, they are not recommended for services with unscrubbed digester gas because of potential problems with sulfide corrosion. Heat recovered from the engine jacket is typically used to sustain the digestion process and for space heating.

Reciprocating engines commonly employed in this application fall into two categories; dual-fuel (compression ignited) and spark ignited engines. Dual-fuel engines use a blend of diesel fuel and digester gas; the fraction of diesel fuel can be varied from a minimum of 4 percent all the way to 100 percent of the mixture. Dual-fuel engines are typically used if there is insufficient digester gas to satisfy power demands. Dual-fuel engines have been specified for new installations where digester gas production is expected to lag behind power demands for several years.

Spark-ignited engines are generally used when there is sufficient digester gas to satisfy power demands. Spark-ignited engines can operate on several different types of fuel (for example. digester gas and natural gas). Special carburetors are provided to blend digester gas with an air-diluted backup fuel (for example. natural gas) during infrequent periods when not enough digester gas is available to satisfy power requirements. Spark-ignited engines are less complex then dual-fuel engines. are available in smaller sizes. and are less costly to operate since expensive diesel fuel is not required.

Natural aspirated feed systems are preferred to turbocharged systems for spark-ignited engines. Turbocharged systems require that gas be delivered at high pressure. which means the gas must be first compressed. then delivered through a fuel metering system with restricted openings. Gas impurities (oils. greases. and water) are condensed when the gas is compressed and cooled; these impurities often clog the fuel metering system. Naturally aspirated systems operate at low pressures ((0.5 psig). With careful design of the gas transport systems. compression of the feed gas is not required. Low pressure fuel metering systems also have relatively large openings compared to metering systems used with turbocharged units. For these reasons. naturally-aspirated fuel systems are therefore less susceptible to clogging than systems with turbocharged units.

Engines represent a large capital investment and should be conservatively designed to protect that investment. For four-stroke engines it is recommended that brake mean effective pressure (BMEP) not exceed 80 to 85 psig to minimize strain on the quipment. Engine speeds in the 700 to 1.000 rpm are preferred as are average piston speeds in the range of 1.200-1.500 feet per minute (370 to 460 m/min). Heavy-duty industrial engines should be specified. not automotive engines.

One of the major problems associated with recovering heat from digester gas is corrosion caused by SO2 and SO3. the combustion products of H2S. If the exhaust gas temperature is allowed to drop below its dewpoint. the condensate which forms is acidic as the result of absorbing SO2 and SO3. The acidic condensate is corrosive to metallic elements of the exhaust-carrying system. There are two alternatives to alleviate the problem. The first is scrubbing of H2S from the gas before combustion. The second is maintaining the exhaust gas at temperatures considerably greater than its dewpoint. to prevent condensation. This generally requires that the water temperature of any boiler or engine using unscrubbed gas be at least 212 degrees F (100 degrees C). Also. stack gas temperatures should not be allowed to drop below 350 degrees to 400 degrees F (177

degrees to 204 degrees C). Use of unscrubbed digester gas is preferred. Equipment fueled by unscrubbed digester gas should not be used in intermittent service, since condensation will occur each time the unit is shut down. Shutdown should be minimized. Similarly, the equipment should be designed so that even when operated at its lowest loadings, exhaust gas temperatures are sufficiently high to prevent condensation.

Generators may be synchronous or induction types. Synchronous generators are by far the most common. However, in smaller sizes (below 5 or 10 MW) induction units are generally less expensive than synchronous units. They are also easier to maintain since they require no governor or synchronizing equipment. Induction generators have the disadvantage of being unable to operate unless parallelled with synchronous generation, either utility or in-plant. Thus an induction generator by itself cannot be used to provide emergency power.

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APPENDIX B

LITERATURE SURVEY

APPENDIX C

LABORATORY REPORTS

Northern
Engineering and Testing, Inc.

600 SOUTH 25TH STREET
P. O. BOX 30615
BILLINGS, MT 59107
(406) 248-9161

TECHNICAL REPORT

Report to:

BROWN AND CALDWELL
ATTN: MR. BOB HUNTER
28 ANNETTE PARK DRIVE
BOZEMAN, MT 59715

Date: August 3, 1983
Job Number: 83-02
Sheet: 1 of 2
Invoice No.: 01968
Work Order No. 58663

Report of: Chemical Analysis of Chicken Manure

Sample Identification:

On July 26, 1983, these samples of chicken manure were delivered to our laboratory for testing. The volatile and total solids were performed on the samples as received, at 103°C and 550°C, respectively. Aliquots of the original samples were then blended to form a paste consisting of three parts water and one part sample. The pH, water soluble sodium, ammonia and nitrogen tests were performed on the 3:1 pastes. The results, except pH, were calculated to an "as received" basis. The results are shown on the following page.

Reviewed by _____

AS A MUTUAL PROTECTION TO CLIENTS, THE PUBLIC AND OURSELVES, ALL REPORTS ARE SUBMITTED AS THE CONFIDENTIAL PROPERTY OF OUR CLIENTS AND AUTHORIZATION FOR PUBLICATION OF STATEMENTS, CONCLUSIONS OR EXTRACTS FROM OR REGARDING OUR REPORTS IS RESERVED PENDING OUR WRITTEN APPROVAL. SAMPLES WILL BE DISPOSED OF AFTER TESTING IS COMPLETED UNLESS OTHER ARRANGEMENTS ARE AGREED TO IN WRITING.

NORTHERN ENGINEERING AND TESTING, INC.
BILLINGS, MT

BROWN AND CALDWELL
BOZEMAN, MT

CHEMICAL ANALYSIS OF CHICKEN MANURE

August 3, 1983
Job No. 83-02
Sheet 2 of 2

Lab No.	pH	Total Solids, % 550°C	Volatile Solids, % 103°C	Water Soluble Sodium ppm - solid	Ammonia N/NH_3 %	Total Kjeldahl Nitrogen %
68619	8.8	46.70	15.78	1115.0	1.11	1.27
68620	8.6	41.03	17.98	1575.0	1.31	1.43
68621	8.8	29.77	14.36	989.1	1.47	1.42
68622	8.0	22.54	15.92	697.2	1.05	1.33
68623	7.8	21.49	15.96	472.8	1.05	1.22
68624	8.4	25.45	18.74	673.2	1.06	1.39

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TECHNICAL REPORT

Revised: August 16, 1983
Date: August 3, 1983
Job Number: 83-920
Sheet: 1 of 2
Invoice No.: 01968
Work Order No. 58663

Report to:

BROWN AND CALDWELL
ATTN: MR. BOB HUNTER
28 ANNETTE PARK DRIVE
BOZEMAN, MT 59715

Report of: Chemical Analysis of Chicken Manure

Sample Identification:

On July 26, 1983, these samples of chicken manure were delivered to our laboratory for testing. The total solids and volatile solids were performed on the samples as received, at 103°C and 550°C, respectively. The total solids and the volatile solids are each calculated on the basis of a percentage of the original weight. Aliquots of the original samples were then blended to form a paste consisting of three parts water and one part sample. The pH, water soluble sodium, ammonia and nitrogen tests were performed on the 3:1 paste. The results, except pH, were calculated to an "as received" basis. The results are shown on the following page.

Reviewed by_____

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NORTHERN ENGINEERING AND TESTING, INC.
BILLINGS, MT

BROWN AND CALDWELL
BOZEMAN, MT

Revised: August 16, 1983
August 3, 1983
Job No. 83-920
Sheet 2 of 2

CHEMICAL ANALYSIS OF CHICKEN MANURE

Lab No.	Identification	pH	Total Solids, % of Sample as rec'd 103°C	Volatile Solids, % of Sample as rec'd 550°C	Water Soluble Sodium ppm - solid	Ammonia N/NH_3 %	Total Kjeldahl Nitrogen %
68619	Aged Manure #1	8.8	36.70	15.78	1115.0	1.11	1.27
68620	Aged Manure #2	8.6	41.03	17.98	1575.0	1.31	1.43
68621	Aged Manure #3	8.8	29.77	14.36	989.1	1.42	1.47
68622	Fresh Manure #1	8.0	22.54	15.92	697.2	1.05	1.33
68623	Fresh Manure #2	7.8	21.49	15.96	472.8	1.05	1.22
68624	Fresh Manure #3	8.4	25.45	18.74	673.2	1.06	1.39

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TECHNICAL REPORT

Report to:

BROWN & CALDWELL
ATTN: MR. BOB HUNTER
28 ANNETTE PARK DRIVE
BOZEMAN, MT 59715

Date: October 5, 1983
Job Number: 83-920
Sheet: 1 of 1
Invoice No.: 03485
Work Order No. 32570

Report of: Manure Analysis

Sample Identification:

On September 15, 1983, five samples were delivered to our laboratory for analysis. Tests were performed according to EPA Publication 600/4-79-020, "Methods for Chemical Analysis of Water and Wastes." The results are as follows:

TEST RESULTS:

Lab No.: Identification:	69553 Fresh Manure	69554 Reactor I Contents	69555 Reactor II Contents	69556 Reactor III Contents	69557 Reactor IV Contents
Total Solids	28.3%	10.6%	2.67%	13.4%	2.16%
Total Volatile Solids	20.9%	4.95%	1.76%	8.17%	1.38%
pH, standard units	6.7	8.6	7.3	8.5	7.0
Sodium as Na, mg/kg	844	889	383	317	250
Total Kjeldahl Nitrogen, mg as N/gm solid	16.5	9.53	4.37	9.33	4.16
Ammonia, mg as N/g solid	8.09	6.85	3.42	5.83	2.95

Reviewed by Kathleen A. Smith

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TECHNICAL REPORT

Report to:

BROWN & CALDWELL
ATTN: MR. BOB HUNTER
28 ANNETTE PARK DRIVE
BOZEMAN, MT 59715

Date: December 8, 1983
Job Number: 83-920
Sheet: 1 of 1
Invoice No.: 07801

Work Order No. 0034

Report of: Animal Waste Analysis - Methane Generation Study

Sample Identification:

On October 27, 1983, four samples were delivered to our laboratory for analysis. Tests were performed according to EPA publication 600/4-79-020, "Methods for Chemical Analysis of Water and Wastes." The results are as follows:

TEST RESULTS:

Lab No.: Identification:	70246 Reactor I Contents	70247 Reactor II Contents	70248 Reactor III Contents	70249 Reactor IV Contents
Total Solids	9.58	4.09	9.67	3.84
Total Volatile Solids	4.79	2.85	6.28	2.68
pH, Standard units	8.4	7.8	8.3	7.7
Sodium as Na, mg/kg	588	188	165	164
Total Kjeldahl Nitrogen as N, mg/gm	9.8	4.5	8.0	4.6
Ammonia Nitrogen as N, mg/gm	8.0	4.4	7.4	3.8

Reviewed by _____

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TECHNICAL REPORT

Revised: 1/24/84
Date: December 20, 1983
Job Number: 83-920
Sheet: 1 of 1
Invoice No.: 07888
Work Order No. 0082

Report to:

BROWN & CALDWELL
ATTN: MR. BOB HUNTER
28 ANNETTE PARK DRIVE
BOZEMAN, MT 59715

Report of: Chemical Analysis of Animal Waste

Sample Identification:

On November 14, 1983, one sample of animal waste was delivered to our laboratory for analysis. Tests were performed according to EPA Publication 600/4-79-020, "Methods for Chemical Analysis of Water and Wastes." The results are as follows:

TEST RESULTS:

Lab No.:	70378
Identification:	Chicken Manure
Date Sampled:	None Given
Total Solids, %	30.0
Total Volatile Solids, %	20.4
pH, standard units	7.0
Water Soluble Sodium as Na, mg/kg	1260
Total Kjeldahl Nitrogen as N, mg/gm	19
Ammonia Nitrogen as N, mg/gm	5.0

Reviewed by Kathleen Adams

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TECHNICAL REPORT

Report to:

BROWN & CALDWELL
ATTN: MR. BOB HUNTER
28 ANNETTE PARK DRIVE
BOZEMAN, MT 59715

Date: December 27, 1983
Job Number: 83-920
Sheet: 1 of 1
Invoice No.: 07908
Work Order No. 0098

Report of: Manure Analysis - Methane Generation Study

Sample Identification:

On November 29, 1983, three samples were delivered to our laboratory for analysis. Tests were performed according to EPA Publication 600/4-79-020, "Methods for Chemical Analysis of Water and Wastes." The results are as follows:

TEST RESULTS:

Lab No.: / Identification: / Date Sampled:	70726 Dilution Water None Given	70727 Reactor Contents II None Given	70728 Reactor Contents III None Given
Total Solids, %	--	5.38	11.8
Total Volatile Solids, %	--	3.39	7.48
pH, Standard units	6.4	8.4	8.7
Sodium as Na, mg/kg	4.8	330	540*
Total Kjeldahl Nitrogen, mg as N/gm solid	--	6.9	13
Ammonia, mg as N/gm solid	--	5.2	11
Total Phosphorus as P, mg/kg	--	2320	3450
Total Dissolved Solids, mg/l	226	--	--
Specific Gravity, gm/cm^3	--	0.99	1.04

*Verified

Reviewed by _____

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MONTANA FARMS

BIO-GAS EXPENSE

through

October 31, 1984

Supplies	184.91
Electricity	298.04
Health Insurance	38.83
Workers' Compensation	82.64
Professional Services	73.18
Payroll Tax	113.92
Unemployment Tax	7.10
Travel	2,097.33
Labor	1,652.66
Total Cost	4,548.61

20 copies of this public document were published at an estimated cost of $8.00 per copy, for a total cost of $160.00, which includes $160.00 for printing and $.00 for distribution.